JUN 8 1967

Physiol, [illegible] (Geol)

GEOLOGY

A geologic reconnaissance in the southeastern

MOJAVE DESERT

California

CALIFORNIA DIVISION OF MINES AND GEOLOGY
SPECIAL REPORT 83

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A Geologic Reconnaissance in the

Southeastern Mojave Desert

California

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Special Report 83
California Division of Mines and Geology
Ferry Building, San Francisco, 1964

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ABSTRACT

The area mapped in this geologic reconnaissance, about 3,500 square miles of the southeastern Mojave Desert in San Bernardino County, California, contains predominantly Cenozoic volcanic and sedimentary rocks in the northwestern half and principally pre-Cenozoic plutonic and metamorphic rocks in the southeastern half. The reconnaissance was concerned primarily with the distribution and lithology of the Cenozoic rocks; the older rocks and the economic resources of the area were studied in less detail.

Moderately rugged mountains form northwest-trending ranges that are flanked by broad gravel slopes, some of which are pediments. Several large dry lakes occupy the main valley floors. The distribution of the mountains and valleys is governed principally by geologic structure and not by composition of the bedrock.

The pre-Tertiary rocks consist of gneiss, schist, and limestone of Precambrian and Paleozoic ages, and metavolcanic rocks of Mesozoic(?) age; all are intruded by plutonic quartz monzonite and granodiorite of late Mesozoic age.

All of the Tertiary rocks, and some of the rocks of either Tertiary or Quaternary age, are restricted to their original basin of deposition in the northwestern part of the area. They are everywhere separated from older and younger rocks by a pronounced angular unconformity. Most of the rocks in this group are volcanic although there are some interbedded sediments. Because of their complex and abruptly changing lithology, and their isolation in separate mountain ranges between which correlation is difficult, these rocks are discussed under four separate geographic areas: the northern Bullion, southeastern Cady, northern Cady, and Bristol and Old Dad Mountains.

In the northern Bullion Mountains quartz latite porphyry intrudes a section of pyroclastic rocks, basalt, and overlying thick andesite flows. A younger sequence of gravels and volcanic rocks, isolated within the range by faults and alluvium, is overlain in angular unconformity by sedimentary rocks and tuffs that are capped by rhyolite tuff with distinctive opalescent blue sanidine phenocrysts. In the southeastern Cady Mountains, pyroclastic rocks and basalt and overlying andesite flows are correlative with the lower units of the northern Bullion Mountains. These are overlain in angular unconformity by welded rhyolite tuff, which in turn is overlain in angular unconformity by lacustrine sediments that contain celestite. The only dated Tertiary beds occur in the northern Cady Mountains, isolated from all other older Cenozoic rocks. Early or middle Miocene vertebrate fossils were found in tuffaceous sandstones that grade westward, through coarse volcanic conglomerates and very coarse andesitic breccias, into basic and intermediate lava flows. In the northern Bristol Mountains, a volcanic complex consisting of andesitic agglomerates, breccias, and tuffs, volcanic conglomerates, and andesite and basalt flows, is overlain by a tilted section of pyroclastic rocks and granitic gravels with an interbedded basalt flow. In both the Bristol and Old Dad Mountains the complex is overlain by rhyolite flows and tuffs, and associated perlite and pumice. The rhyolite tuff contains opalescent blue sanidine phenocrysts and is identical with the rhyolite tuff of the northern Bullion Mountains, with which it may correlate.

The remaining "Tertiary or Quaternary" rocks, and all of the Quaternary rocks, are distributed throughout the mapped area. They consist of gravels, alluvium, playa sediments, basalts, and wind-blown sand. Near Twentynine Palms and at the southeastern corner of the Pinto Basin, clastic sediments have yielded Pleistocene(?) vertebrate remains. The gravel deposits have been divided on the basis of physiographic position into: (1) tilted gravels; (2) high gravels, that are generally flat-lying but are unrelated to present drainage; (3) older alluvium, that is related to present drainage but is being dissected; and (4) modern alluvium of dry washes and alluvial fans. Four late Quaternary basalt flows retain their cinder cones virtually uneroded. Lava poured from the Pisgah and Amboy craters onto playa surfaces. Sand dunes, one over 700 feet high, have formed at the southeastern ends of the basins and valleys.

Faulting and tilting were the dominant tectonic activities during the Cenozoic; folding was minor and generally related locally to faults. Northwest-trending faults, possibly of right lateral displacement, are greatly predominant, especially in the western part of the area. Three east-trending faults, two in the Cady Mountains and one along the north face of the Pinto Mountains, disrupt the regional northwest trend. An earthquake caused by `left lateral displacement occurred on the east-trending Manix fault in 1947.

The economic products of the area are predominantly saline minerals (sodium chloride, calcium chloride, sodium sulfate, gypsum, and celestite), light-weight aggregates (volcanic cinders, perlite, and pumice), and clays (bentonite and hectorite). Gold, iron, copper, and manganese have also been produced.

A geologic reconnaissance in the southeastern Mojave Desert, California †

By Allen M. Bassett and Donald H. Kupfer

INTRODUCTION

Location and accessibility. The southeastern Mojave Desert is a very dry and sparsely inhabited region in which the geology has remained almost totally unknown to the time of this reconnaissance. The area described in this report, about 3,500 square miles, lies almost wholly within southern San Bernardino County, California, between lat. 34° and 35° N. and long. 115° and 116°30′ W. (fig. 1).

The tracks of the Union Pacific Railroad skirt the area on the north in what is otherwise a relatively inaccessible region. The Atchison, Topeka, and Santa Fe Railway and U.S. Highway 66 run close together across the middle of the area, passing through the railroad towns of Ludlow, Bagdad, Amboy, and Cadiz. The Parker-Phoenix branch of the Santa Fe Railway goes southeast from Cadiz and marks approximately the area's eastern border. A paved highway connects Amboy with Twentynine Palms, the largest town in the region. All other roads in the area are not regularly maintained and are undependable for travel by passenger car. Much of the area near the Bullion Mountains is within the Twentynine Palms Marine Corps Training Center and is closed to public entry.

Physical features. The three distinct parts of mountainous desert physiography are the bedrock mountains, the gravel slopes, and the basin floors, which generally contain playas. Of the area of this reconnaissance (pl. 1) about 45 percent is bedrock, fully half is gravel slope, and 5 percent is playa.

Moderately rugged mountains form discontinuous northwest-trending ranges 25 to 50 miles long and only 2 to 8 miles wide, except where disrupted in the Cady Mountains and Pinto Mountains by east-trending faults. The distribution of the mountains and valleys does not reflect the composition of the bedrock, but instead is principally the result of geologic structure. This is the common situation in the Basin and Range province, of which this is considered a part (Fenneman, 1931; Nolan, 1943). The dominant structural control is exerted by the northwest-trending faults that are responsible for the region's strong northwest linearity. The highest mountains of the area, the northern Granite Mountains,* exceed 6,200 feet in altitude; most of the other ranges rise to altitudes between 3,000 and 3,600 feet above sea level. The lowest point is in Cadiz Dry Lake at an altitude of 540 feet.

The center of the area is dominated by the "great trough that extends from Barstow southeastward almost to Colorado River" (Thompson, 1929, p. 652). This trough consists of a series of valleys and basins connected either directly or by low passes. South of this trough, northwest-trending ranges, including the Bullion, Sheep Hole, Coxcomb, Calumet, and Iron Mountains (fig. 1), are alined en echelon to form part of a long topographic high that extends nearly 200 miles from the western Mojave Desert east-southeastward to the Colorado River (fig. 2). This topographic high was apparently present during the deposition of the older Cenozoic rocks as it appears to have formed the southern border of the basin of deposition. Another parallel trough lies south of this topographic high and includes the valley with Twentynine Palms and Dale Dry Lake. These indistinct warps have been greatly modified by faulting and erosion.

The gravel slopes are many miles across. Their gradient is consistently a little over 2° from mountain front to valley floor, flattening from slightly more than 3° in the uppermost mile. Most of these slopes are cut by strongly braided rills. A major channel emerging from a moun-

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† Publication authorized by the Director, U.S. Geological Survey. The map and report were prepared while the authors were members of the Survey.

* There are two mountain ranges in the mapped area called the Granite Mountains. For convenience in this report, they are distinguished by calling one range the "northern Granite Mountains", and the other the "southern Granite Mountains" as shown on figure 1.

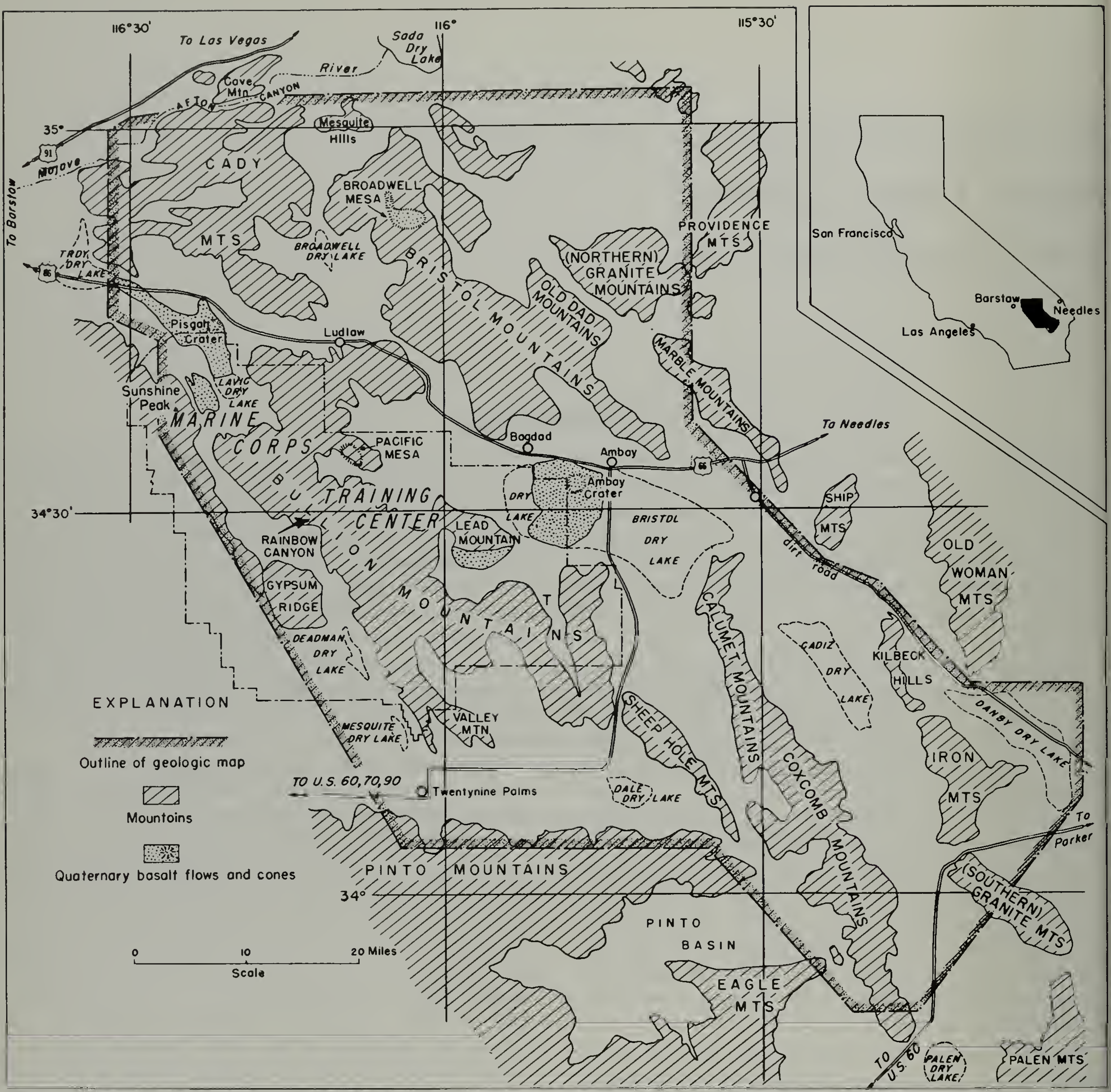


Figure 1. Index map showing location of area mapped and the geographic names used in this report.

tain front divides into many lesser but still discernible channels and these disintegrate downhill into a scatter of smaller distributaries.

Many of the gravel-covered slopes are actually pediments, especially in regions underlain by homogeneous plutonic rocks. They are most common along the mountain fronts although some extend well up into the core of the range. Several of these pediments have been exhumed and are now being dissected.

More than a dozen playas occupy the undrained lower parts of the larger basins or are perched in some of the small enclosed valleys within the mountains. The largest and most prominent are Bristol, Cadiz, and Danby Dry Lakes.

Four basalt flows of Recent age, that still have well-formed cinder cones, occur in the valleys. Large areas are covered by sheets and dunes of wind-blown sand.

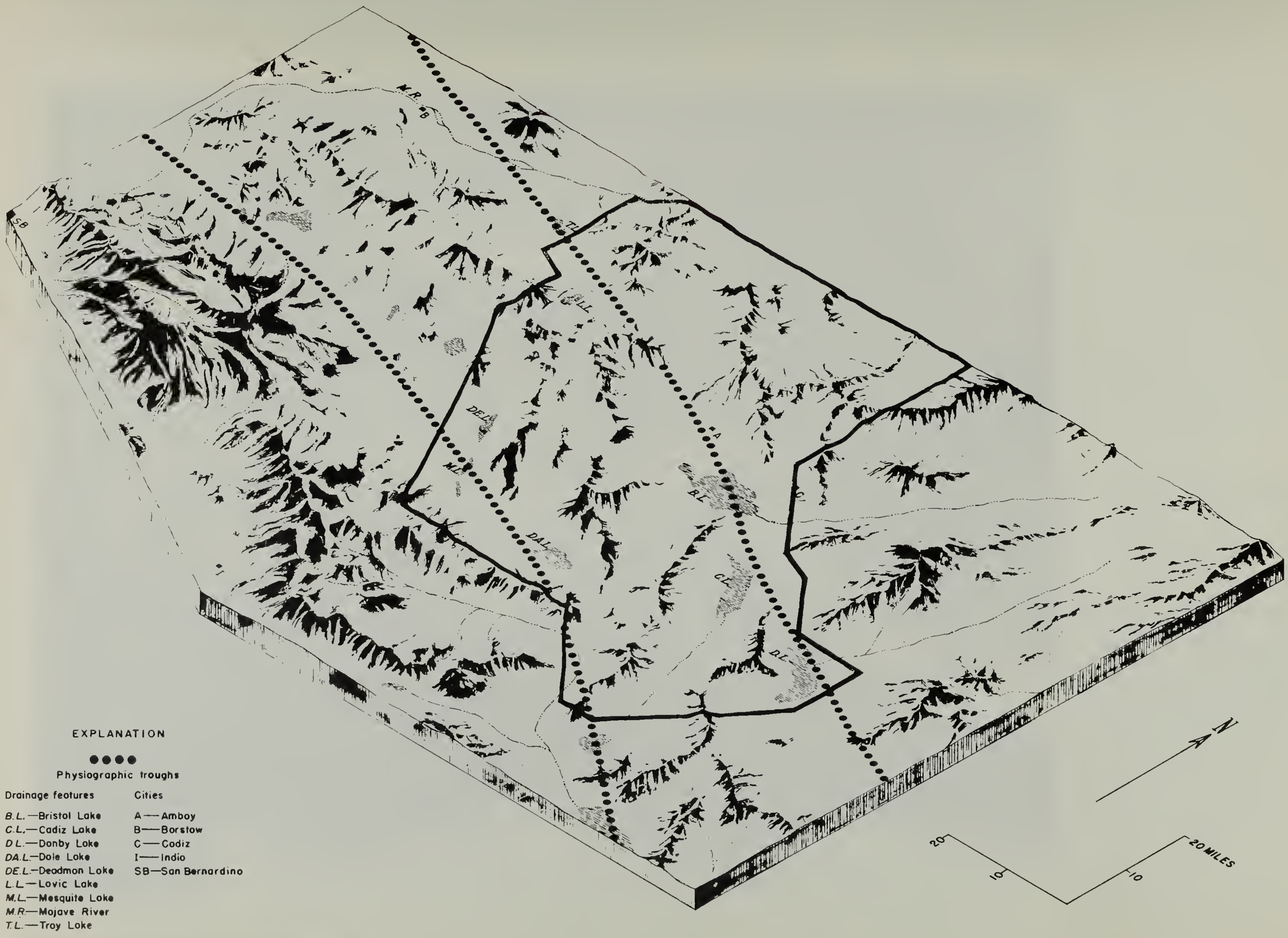


Figure 2. Isometric sketch map of the southeastern Mojave Desert, showing physiographic troughs and outline of geologic map.

Photo 1. View west from Mitchell Caverns in the Providence Mountains. Though this cactus "garden" is close to the edge of the mapped area (the crest of Providence Mountains is in the background), actually, few cacti are found within its boundaries. *Photo by Mary Hill.*

Climate and vegetation. This area is in one of the driest parts of the United States—it has an average annual rainfall of about 4 inches (Troxell and Hofmann, 1954). The climate is one of extremes, characterized by intense heat in the summer, often reaching temperatures in excess of 120°F, and strong cold winds during the late winter and spring, when dust storms are common. Summer thunderstorms are infrequent but severe, commonly damaging both roads and property. Winter snows are very rare. There is no surface runoff except during storms and no external drainage whatsoever.

The vegetation is of the Upper Sonoran Zone, very lightly scattered on most rock outcrops, absent on the playas, and sparse but evenly spaced on the alluvial slopes. Creosote bush (*Larrea tridentata*) is by far the most abundant plant in the region, but small plants of the buckwheat and pea families are also common. Smoketree occurs in many dry washes, and mesquite and salt grasses grow densely around springs. Along a water seep on the Pinto fault is a stand of native desert palms (*Washingtonia*), for which the town of Twentynine Palms was named. Joshua trees and yucca are abundant just west and south of Twentynine Palms, in the Joshua Tree National Monument, but few grow within the area mapped. Juniper and pinyon pine are limited within the area to the northern Granite Mountains. Palo Verde trees have been planted at many highway bridges; tamarisk, introduced from the Colorado River area, is the most popular shade tree. Cactus plants are not common.

Mineral commodities. No special study was made of the mines and mineral resources of the area during this reconnaissance. Previous investigators have described the mineral deposits in the area as a part of commodity studies. These include the examinations for iron by Lamey (1948), for salines by Gale (1951) and Ver Planck (1954 and 1957), for strontium by Durrell (1953a and 1953b), for gypsum by Ver Planck (1952), for perlite by Jaster (1956), and for water by Thompson (1929) and by the California Division of Water Resources (1954). Lists of the individual mines and prospects of the area and brief descriptions of many of them are included in the resource studies for San Bernardino County (Wright and others, 1953). An older survey of a larger area was made by the U. S. Geological Survey (Hewett and others, 1936).

Commodities reported to have been worked commercially within the area of this reconnaissance include salt, calcium chloride, sodium sulfate, gypsum, celestite, barite, perlite, cinders, pumice, sand and gravel, limestone, hectorite, bentonite, gold, iron, copper, and manganese. The localities where these occur are described by Wright and others (1953).

Previous work and acknowledgments. Results of a hydrologic reconnaissance of the Mojave Desert region by David G. Thompson from 1917 to 1921 were published as a geologic report and map (Thompson, 1929). This remained the only published geologic work on most of the area of the present report until the hydrologic study by geologists of the California Division of Water Resources (1954), which resulted in a Geologic Reconnaissance Map. The geological map of California (Jenkins, 1938) derived its information on this area mainly from Thompson's report but also from the mapping of J. C. Hazzard, which is unpublished, and Gardner (1940), both of which extend partly into the area covered in the present report.

The published geologic works of detailed nature within the area consist of a report on saline deposits of Bristol Dry Lake by Gale (1951), a study of celestite deposits in the Cady Mountains and in Bristol Dry Lake by Durrell (1953a), a description of the saline deposits of Bristol, Cadiz, Danby and Dale Dry Lakes by Ver Planck (1957), and a report on core logs from Bristol, Cadiz and Danby Dry Lakes by Bassett, Kupfer, and Barstow (1959).

Mineralogic and petrographic examination of about 40 rock specimens, described in this report, were made by Robert D. Allen of the U. S. Geological Survey. For this assistance the authors are especially grateful.

The authors wish to acknowledge with gratitude the cordial help offered them by many people of the desert. In particular, they wish to thank Mr. and Mrs. Noel Edwards of Twentynine Palms, Mrs. E. V. Howell and Mr. Earl Warnix at Ludlow, Mr. M. M. Stephans at Amboy, and the Riddles at Chambless. The authors also wish to thank the U. S. Marine Corps for permission to examine the area included within their base near Twentynine Palms.

Objectives and mapping method. The purpose of the mapping was to make a brief and rapid survey of a relatively unknown area in order to determine the general types and distribution of the Tertiary rocks and the regional structure, so that specific areas could be delimited where further field work would be most likely to yield the details needed to solve regional problems.

The report is on four separate areas, between which the older Cenozoic rocks could rarely be correlated, and as a result, a multiplicity of map units is unavoidable. When more detailed mapping is done and correlations are made between the separate ranges, the number of map units might be reduced.

The mapping was done during July, August, and September, 1953. The geology was mapped initially on aerial photographs and later transferred to topographic maps. Field observations were made wherever jeeps could gain access, generally along dry washes and mountain edges.

The topographic base was furnished by the Metropolitan Water District of southern California from planetable maps made of the entire southeastern desert area of California from 1925 to 1928 in anticipation of the Colorado River Aqueduct project. The topography on these maps is moderately good in the lower and flatter country, but is generalized in the high and rugged areas. No more recent topographic maps were available at the time the field work was done, but since then the entire area has been mapped in 7½ or 15-minute quadrangles by the U. S. Geological Survey.

The geology was transferred from the aerial photographs to the available base map, with adjustment of geologic contacts where possible to fit the topography. Where the topography was seriously incorrect, it was ignored. The traces of faults, which are nearly straight lines in this area, were maintained at approximately their true trend and, where necessary, without respect to local topography. Because the geologic contacts have been traced with great detail from air photographs, the resulting map (pl. 1) gives the impression of having a refinement much beyond that possible by such rapid and incomplete field mapping.

Most of the rocks were identified in the field with a hand lens, but about 40 specimens of volcanic and plutonic rocks were examined in the laboratory by Robert D. Allen, U. S. Geological Survey. Ground portions of each rock were immersed in index oils and examined under the microscope to determine the mineral composition of the larger grains and, for the volcanic rocks, the approximate index of refraction of the glass or very fine-grained groundmass.

ROCK UNITS

On the geologic map (pl. 1), the rocks of the southeastern Mojave Desert have been divided into four groups according to their inferred age: "pre-Tertiary", "Tertiary", "Tertiary or Quaternary", and "Quaternary". These ages are uncertain and somewhat arbitrary because the periods of deposition, erosion, and diastrophism indicated by mapping appear almost randomly distributed in time, and generally cannot be tied closely to the time scale. Only two dates are established on fossil evidence, and those are in isolated localities where the rocks cannot be correlated with the principal stratigraphic sequences.

To simplify discussion in this report, the individual map units are redivided into three groups. The groups are separated by two pronounced regional unconformities (indicated on the explanation of pl. 1), one between the "pre-Tertiary" and "Tertiary" rocks, and one in the middle of the "Tertiary or Quaternary" rocks. The oldest group comprises the "pre-Tertiary" plutonic and metamorphic rocks. The second group comprises all of the "Tertiary" and some of the "Tertiary or Quaternary" rocks, most of which are volcanic although some are sedimentary. For convenience, these are referred to throughout the rest of this report as "older Cenozoic rocks". The third group includes the remaining "Tertiary or Quaternary" rocks and all of the "Quaternary" rocks, most of which are gravels, alluvium, and playa deposits, but some are basalt. These are referred to throughout this report as "younger Cenozoic rocks".

In this report, formation names have not been used because it is felt that the rock units are inadequately mapped. Where a specific rock unit is discussed, especially where the context or terminology do not clearly define the unit, the map symbol is added in parentheses.

PRE-TERTIARY ROCKS

Inasmuch as the principal emphasis of this study was on the Cenozoic rocks, only minor attention has been given to the pre-Tertiary rocks that form a "basement complex" in the area. They were only crudely differentiated where this could be done easily and quickly; generally this was by inspection of the aerial photographs with only spot checks in the field. Metamorphic rocks have been distinguished from plutonic rocks in most instances, but a symbol (pm) has been used to designate areas of rock either known to be pre-Tertiary though not differentiated as to plutonic or metamorphic, or known to be composed of both in nearly equal amounts.

Metamorphic rocks

There are no thick and well-stratified sections of Paleozoic or Precambrian rocks like those to the north and northeast of this area (Hazzard, 1954; Grose, 1959; Hewett, 1956). Instead, most of the metamorphic rocks occur in scattered areas of relatively limited extent, frequently surrounded by plutonic rocks, seldom well stratified, and usually intensely metamorphosed and injected.

The metamorphic rocks were generally undifferentiated (m), but in the southeastern part of the area and in the northern Cady Mountains, a distinction was made between rocks with a marked foliation or similar planar metamorphic structure (mf), and those with a more gneissic structure (mg), as well as limestones (ml) and metavolcanic rocks (mv).

The category of foliated metamorphic rocks (mf) includes schist, slate, and phyllite, as well as nonfoliated granulite, and quartzite. Harder (1912), Hazzard (1933), and Miller (1944) described these rocks in the southeastern part of the area. Hazzard, Gardner, and Mason (1938) reported the occurrence of folded conglomerates, sandstones, shales, limestones, and acid volcanic flows and tuffs, of probable Triassic age, which have been intruded by Jurassic(?) quartz monzonite at the southern end of the Coxcomb Mountains (fig. 1). These outcrops were not studied by the present authors.

The gneissic metamorphic rocks (mg) consist of true gneisses as well as lit-par-lit or migmatitic intermixtures of metamorphic and granitic rock. The gneissic rock

Photo 2. The Granite Mountains. *Photo by Mary Hill.*

have been distinguished primarily in the southeastern part of the area, but they occur abundantly elsewhere where they are included with the undifferentiated metamorphic rocks (m) and the mixed metamorphic and plutonic rocks (pm).

Metasediments that include a high content of carbonate rock (ml) were noted in several widely scattered areas. The most conspicuous of these, at the north end of the Kilbeck Hills (fig. 1) has been discussed by Hazzard and Dosch (1937), Logan (1947, p. 283), and Wright and others (1953, p. 173). Limestone at the southeast end of the Bristol Mountains has been described by Logan (1947, p. 282-283 and 295-296). Limestone also occurs at the mouth of Afton Canyon.

Metavolcanic rocks (mv) occur in the northern Cady Mountains and in Valley Mountain, and in the southern part of the Coxcomb Mountains (mf). They are generally fine-grained, dark-gray to gray-green rocks, with phenocrysts of quartz and feldspar that locally form 5 to 15 percent of the rock. Some are extensively epidotized. The rocks show considerable variation in composition, but plagioclase feldspar is generally abundant and quartz is common. Biotite and hornblende are the usual accessory minerals. Two samples from Valley Mountain, examined by R. D. Allen, contained, in decreasing order of abundance, oligoclase, potassium feldspar, quartz, and accessory minerals. The accessory minerals in one were biotite, chlorite, an opaque mineral, and sphene; in the other, green hornblende, epidote, hematite, and muscovite.

Plutonic rocks

The plutonic rocks are subdivided into the light-colored rocks (pl) and the dark-colored rocks (pd). Most of the lighter rocks of the area are equigranular or porphyritic quartz monzonite, but granodiorite is also common and many other rock types are present. Most of the reports on the geology of the surrounding areas contain descriptions of these rocks (Gardner, 1940, p. 263-276; Miller, 1946, p. 473-474 and 492-502; Rogers, 1954 and 1958). The dark rocks (pd) have been mapped separately in a few places, but they were not specifically studied. Most of them appear to be hornblende diorites, but some may be migmatites. Granitic and aplitic dikes occur in several areas, particularly the northern Granite Mountains.

Four representative samples of the granitic rocks of the area collected by R. C. Ellis are classified as quartz monzonite on the basis of quantitative modal analyses of the rocks by point counting thin sections (table 1).

Ages of pre-Tertiary rocks

Most of the geologists who have worked in the region have recognized the presence of both Precambrian and

Table 1. Quantitative modal analyses of selected granitic rocks of the southeastern Mojave Desert.

	RCE 54-7-19A percent	RCE 54-7-26A[1] percent	RCE 54-7-27A percent	RCE 54-7-27B percent
Quartz	28.8	19.2	28.2	29.6
Potassium feldspar	31.7 [2]	31.1 [3]	32.2 [2]	29.5 [2]
Plagioclase	35.2 [4]	45.0 [5]	35.1 [6]	38.4 [4]
Biotite	2.1	3.2	1.95	0.5
Muscovite	1.0	0.05	1.2	1.8
Opaque	0.5	0.85	0.55	0.1
Apatite	0.1	0.3	trace	-----
Zircon	trace	0.1	trace	-----
Epidote	-----	-----	0.1	-----
Chlorite	0.5	0.1	0.7	0.1
Limonite	0.1	-----	-----	-----
Leucoxene	-----	0.1	-----	-----
	100.0	100.0	100.0	100.0

[1] Rock containing cross-cutting pegmatites with age of 155 million years or Middle Jurassic (Hewett and Glass, 1953, p. 1046).
[2] Orthoclase.
[3] Orthoclase and microperthite.
[4] Oligoclase, myrmekitic in minor degree.
[5] Oligoclase and antiperthite.
[6] Sodic andesine, myrmekitic in minor degree.
Analyst, R. D. Allen, U. S. Geological Survey.
Locations:
RCE 54-7-19A Near telephone line at southeastern corner of the northern Granite Mountains, 15 miles north-northeast of Amboy, California.
RCE 54-7-26A Near the pegmatite sampled by Hewett and Glass (1953), in the central Cady Mountains.
RCE 54-7-27A Just south of summit of pass on main highway between Amboy and Dale Dry Lake, Sheep Hole Mountains.
RCE 54-7-27B At the northeastern edge of the Coxcomb Mountains and on the gravel road from Dale Dry Lake to Rice, California.

Mesozoic plutonic rocks (Gardner, 1940, p. 276; Nolan, 1943, p. 145; Longwell, 1950, p. 427). The only radioactively dated plutonic rock in the mapped area is a pegmatite that has intruded quartz monzonite in the central Cady Mountains. Betafite in the pegmatite has been determined by the lead-uranium method to be 155 million years old, or of Middle Jurassic age (Hewett and Glass, 1953, p. 1046). Euxenite, a pegmatite mineral from the Pomona Tile Quarry, just southwest of the mapped area, has been dated as being about 150 million years old (Hewett and Glass, 1953, p. 1049). Three samples of plutonic rocks collected just outside of the mapped area (Pomona Tile Quarry, Providence Mountains, and White Tanks) have been dated by the lead-alpha method as 89, 94, and 116 million years old, or of Cretaceous age (Jaffe and others, 1959, nos. 110, 112, and 116). The relative ages of the crosscutting pegmatite and host rock samples collected from the Pomona Tile Quarry are inverted from the order expected, casting doubt on one or the other age determination.

The metamorphic rocks of the desert region are of Precambrian, Paleozoic, and Mesozoic age (Nolan, 1943, p. 145, and many others), but none of the metamorphic rocks within the area of this reconnaissance have been accurately dated. The Cambrian rocks noted by Clark (1921) as being in the Bristol Mountains are actually in the mountains now known as the Marble Mountains (fig. 1) (Hazzard, 1933, p. 57-58). The metavolcanic rocks of the region are generally considered to be Mesozoic (Gardner, 1940, p. 270; Hazzard, Gardner, and Mason, 1938) but it is possible that some of them may be Paleozoic (Miller, 1944, p. 52). The metavolcanic rocks of this mapped area are undated. However, they are thought to be correlative with the metavolcanic flow breccias and sandstones of the Soda Mountains, about 20 miles north of this reconnaissance, which have been dated by Grose (1959, p. 1527-1528) as Triassic or Jurassic on the basis that they disconformably overlie fossil-dated Lower Triassic beds and are intruded by Cretaceous plutonic rocks.

OLDER CENOZOIC ROCKS

The older Cenozoic rocks of the southeastern Mojave Desert are dominantly volcanic with a volumetric preponderance of pyroclastic material. Correlation of the rocks of one range with those of another is hazardous in this volcanic province. Although a few such correlations are made, and the same rock symbol is used in both ranges, most correlations should not be made until more detailed mapping is undertaken. With this in view, the rocks are discussed under four separate geographic locations: the northern Bullion Mountains, southeastern Cady Mountains, northern Cady Mountains, and the Bristol and Old Dad Mountains (figs. 1 and 3).

The age of the older Cenozoic rocks is known only in the northern Cady Mountains, where fossils indicate an early or middle Miocene age. However, because of the degree of faulting, tilting, and erosion, and because of the similarity to rocks that are dated as Miocene or Pliocene in adjacent parts of the desert, most of the unfossiliferous older Cenozoic rocks are also believed to be of Tertiary age. A multiple time symbol (QT) has been used for a few of the younger-looking units to emphasize the possibility of their being in part of Quaternary age.

Photo 3. The Marble Mountains. *Photo by Mary Hill.*

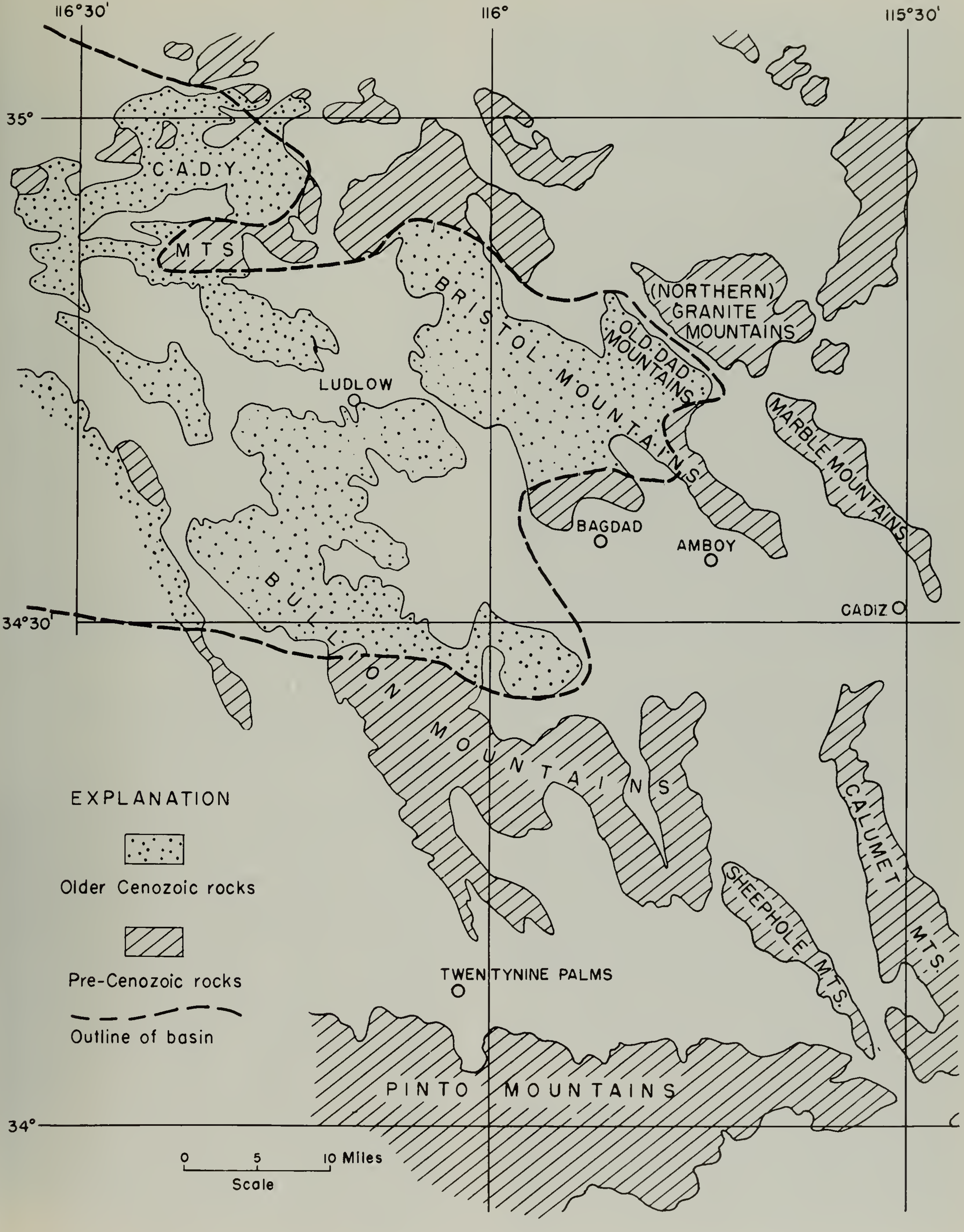


Figure 3. Outline of the older Cenozoic basin of deposition within the southeastern Mojave Desert.

The older Cenozoic rocks are restricted to the northwestern part of the mapped area (pl. 1). Here they occupy part of an older Cenozoic basin of deposition that shoaled against basement rocks on the northeast, east, and south, but extended west and northwest into the central Mojave Desert (fig. 3). This basin of deposition is nearly 40 miles wide from north to south along the western edge of the reconnaissance area. On the east and northeast sides of the basin, the older Cenozoic deposits thin eastward and lap onto the basement rocks. The southern border of the basin is sharply delimited by the abrupt pinching out of the older Cenozoic formations southward against basement rocks. In the Newberry Mountains, west of the mapped area, a thick deposit of interstratified andesite flows, tuff breccias, and coarse conglomerates of Tertiary age laps against a basement surface of high relief, indicating the depositional basin was bounded by a steep mountain front, (T. W. Dibblee, Jr., written communication, 1957). In the central Bullion Mountains, the Tertiary rocks were also limited by a mountain front of considerable relief. This southern border appears to have been greatly modified at a later period by lateral displacements along northwest-trending faults, especially in the Bullion fault zone and the northward continuation of the Mesquite Dry Lake fault zone; the western parts of the Tertiary basin have evidently been shifted relatively northwestward, perhaps several miles. The western and northern borders of the basin lie beyond the mapped area.

Rocks of the northern Bullion Mountains

The older Cenozoic rocks in the northern Bullion Mountains appear to provide the most continuous and readily decipherable stratigraphic sequence in the area. The stratigraphic relations of the units in this sequence are indicated below.

QTpr

Rhyolite tuff

PROBABLE ANGULAR UNCONFORMITY

QTps

Sedimentary rocks and tuffs

ANGULAR UNCONFORMITY

Tpg

Gravels and volcanic rocks

PROBABLE UNCONFORMITY

Tql

Quartz latite porphyry
(intrusive)

Ta

Andesite

LOCAL DISCONFORMITY

Tp

Pyroclastic rocks and basalt

The lower two units (Tp and Ta) occur together throughout the northern Bullion Mountains (pl. 1). The quartz latite porphyry (Tql) intrudes the andesite along the northern and northeastern edges of the range. The upper three units are exposed only at or near Pacific Mesa, a flat-topped hill 400 feet high and about a third of a square mile in area, located 10 miles south of Ludlow (fig. 1). The rhyolite tuff (QTpr) forms a caprock on the sedimentary rocks and tuffs (QTps) which lie in conspicuous angular unconformity on the tilted and folded sequence of gravels and volcanic rocks (Tpg).

Pyroclastic rocks and basalt (Tp)

The basal unit of Tertiary age in the northern Bullion Mountains is composed of white, green, and pink, well bedded pyroclastic rocks with interbedded scoriaceous basalt flows. These rocks underlie all the northern Bullion Mountains and extend from Rainbow Canyon, where the section is especially well exposed, northward to the hills near Ludlow. They also occur in the southeastern Cady Mountains. The following lithologic description includes the data from both the northern Bullion Mountains and the southeastern Cady Mountains.

Lithology. The general lithology of this unit remains the same throughout its 30 mile length of exposure, but individual layers differ greatly in thickness and lithology from place to place and many pinch out along strike, making accurate detailed correlation very difficult. At the southernmost outcrops, in Rainbow Canyon, the unit consists of pyroclastic rocks of light color and coarse texture with a very few interbedded basalt flows. At the northern limit, in the southeastern Cady Mountains, basalt flows are considerably more abundant. In all areas, the principal pyroclastic rocks are volcanic breccias and agglomerates in which fragments up to 10 inches across are common. Volcanic breccia and agglomerate are used throughout this report for coarse volcanic debris either airborne or transported short distances by water; the breccias are composed of angular fragments, the agglomerates of rounded fragments. Tuffs, although less abundant, form distinctive marker beds. Microscopic inspections of the pyroclastic rocks were too few to be diagnostic, but they suggest that most of the volcanism was intermediate in character (latitic and dacitic). In some places it is difficult to distinguish basalts that occur in this unit from basalts of later age (QTub) that intrude it and overlie it unconformably.

Thickness and representative sections. This unit is at least 300 feet thick in Rainbow Canyon, and it increases in thickness northward. The section along the western front of the northern Bullion Mountains is broken by faulting but is probably about 1,600 feet thick. Gardner (1940, p. 282) describes apparently equivalent rocks to the west (his "Rosamond series") that in places are over 2,000 feet thick. Durrell (1953a, p. 38) gives the thickness of rocks in the southeastern Cady Mountains correlated with this unit as over 1,000 feet.

Following are two representative sections of this unit.

Stratigraphic section in Rainbow Canyon northern Bullion Mountains.

Massive andesites of overlying unit	Estimated thickness (in feet)
G. Well-bedded, light-colored, biotite tuff with pumice fragments (top of sequence)	10– 50
F. Green breccia of closely packed, very angular fragments up to 10 inches across with a minimum amount of dark mafic matrix, some pyrite	10– 20
E. White volcanic breccia, fragments up to 10 inches across, with tuffaceous matrix	30– 50
D. Well-bedded white lithic tuff with biotite and quartz grains, also arkosic sand	10– 20
C. Very light pink to lavender latite(?) agglomerate, 1-inch pumice fragments in a matrix resembling lava	10– 40
B. Tan-weathering volcanic breccia with 6-inch fragments of silicic lava, high content of quartz in matrix	50–100
A. Vesicular and amygdaloidal basalt; very dark and generally green-stained; thickness variable, probably due to accumulation on irregular topography	0– 60
Maximum thickness about	300
UNCONFORMITY	
Quartz monzonite and metamorphic rocks.	

Stratigraphic section in the central portion of the northern Bullion Mountains.
(Section broken by numerous faults)

Andesite of the overlying unit	Estimated thickness (in feet)
E. Pale olive to pale yellowish green pumiceous conglomerate with tuff matrix	50
D. Mafic flows and flow breccias, some pyroclastic rock	700
C. White to pale-green volcanic breccias and agglomerates	75
B. Well-bedded mafic flows and flow breccias (may be unit D repeated by faulting)	500
A. Light greenish-gray to light brownish-gray conglomerates and agglomerates	300(?)
Total thickness possibly	1,625
FAULT	

Relationship to adjacent formations. The unit of pyroclastic rocks and basalt was deposited on the older plutonic and metamorphic rocks of the basement complex. In Rainbow Canyon they were laid down on a surface of moderate relief near the margin of the basin of deposition and the lower layers were deposited only in the topographic lows. The unit is nearly everywhere overlain by thick andesite flows. In many places this contact is conformable, but in others erosion took place before the deposition of the andesite and the relationship is that of local disconformity. Similar evidence of erosion occurs at various horizons within the unit and the erosional interval at the base of the andesite seems to be no greater or more widespread than some of the erosional intervals within the pyroclastic rocks and basalt. In a few places, high gravels (QTh) and undifferentiated basalt flows (QTub) of later age than the andesites rest in angular unconformity on the rocks of this unit.

Andesite (Ta)

Thick andesite flows overlie, with minor or local unconformity, the pyroclastic rock and basalt unit (Tp) with which they are generally coextensive. These flows occur as erosional remnants that cap hills throughout the northern Bullion and southeastern Cady Mountains (pl. 1). Similar andesite occurs in the Bristol and northern Cady Mountains, but because it could not be correlated confidently with the andesites of the northern Bullion Mountains, it has not been shown on the map as an extension of this unit. The following lithologic description includes the data from the southeastern Cady Mountains as well as the northern Bullion Mountains.

Lithology and thickness. The lower part of the andesite unit is a scoriaceous and vesicular dark grey or black volcanic rock. A specimen from the base of the sequence was found to contain about 15 percent microphenocrysts of andesine, with minor amounts of biotite and hornblende, in a groundmass of fine-grained andesine, calcite, hematite, magnetite, and some glass having an index of refraction of 1.50. Durrell, in writing of correlative andesites of the southeastern Cady Mountains, notes that "at several places near the base of the section there is light grey to black, locally vitrophyric, biotite and hornblende andesite" (1953a, p. 38).

The upper part of this unit consists of several thick flows of dark red and maroon porphyritic biotite andesite with euhedral to subhedral phenocrysts of andesine or oligoclase. Durrell (1953a, p. 40) refers to equivalent rocks in the southeastern Cady Mountains as "reddish and gray hypersthene andesite flows". Hypersthene was observed in the andesite of the Bullion Mountains but in the samples examined was not so abundant as in the southeastern Cady Mountains.

West of the mapped area, in the Newberry and Ord Mountains, Gardner (1940, p. 283) noted "yellowish agglomerate and tuff beds" interbedded with the andesite flows, and in the southeastern Cady Mountains, Durrell (1953a, p. 38) noted "local intercalations of tuff and tuff breccia". Only one occurence of pyroclastic material was observed in the andesites of the northern Bullion Mountains, but detailed mapping probably would reveal more.

In the northeastern and northern Bullion Mountains, where this unit appears to be intruded by quartz latite porphyry, a distinction between the intrusive and extrusive rocks cannot easily be made. Here, as well as elsewhere, many of the rocks mapped as andesite flows may actually be intrusive in origin—either as quartz latite porphyry or andesite porphyry. In some areas, particularly around the gold mines of the Stedman district south of Ludlow, flows more silicic than andesite were mapped with the andesite. Some of these lavas may be hydrothermally altered andesites, or they may be original silicic lavas (dacite or even rhyolite).

No accurate measurements of the thickness of this unit have been made. Durrell (1953a, p. 38) estimates that "the andesite is about 600 feet thick near the celestite deposit, and must be several times that thick in the eastern part" of the southeastern Cady Mountains; and Gardner (1940, p. 281) suggests a probable maximum thickness of 1,200 feet in the area west of the Bullion Mountains. The exposed section in the northern Bullion Mountains is probably on the order of 1,000 feet thick.

Relationship to adjacent formations. In general, the andesite rests with minor or local unconformity on the pyroclastic rocks and basalt (Tp), but in a few places erosion has removed the uppermost beds of the pyroclastic sequence and the andesite rests on beds that are lower in the section. Correlative andesite in two places rests directly on plutonic rocks: along the southern front of the central Cady Mountains and in the Newberry and Ord Mountains to the west (Gardner, 1940, p. 281).

In most places the top of the andesite now is exposed to erosion. Where covered, it is overlain unconformably by high gravels (QTh) and undifferentiated basalt (QTub) in the northern Bullion Mountains and the hills south of Ludlow, and by welded rhyolite tuff in the southeastern Cady Mountains (Durrell, 1953a, p. 38).

Quartz latite porphyry (Tql)

Large bodies of quartz latite porphyry crop out in the northwestern corner and along the northeastern slope of the northern Bullion Mountains. Smaller masses occur in the central and southwestern Bristol Mountains and in the northern Cady Mountains; even though they may represent intrusives of different ages, they have been given the same map symbol as those of the northern Bullion Mountains. Even within the northern Bullion Mountains the rock is not everywhere of the same texture or color, and careful mapping may reveal more than one rock type and more than one period of intrusion. Due to its similarity to some of the extrusive volcanic rocks, particularly to the porphyritic andesites, many outcrops of intrusive rock probably have been overlooked in this reconnaissance. Gardner (1940, pl. 2), for example, shows large masses of "monzonite porphyry" in the hills south of Ludlow where none is indicated on plate 1 of this reconnaissance.

Most of the quartz latite porphyry is composed of a pale-red, very fine grained to aphanitic groundmass with 30 to 40 percent medium- to coarse-grained phenocrysts. Among the largest and most abundant phenocrysts are lath-shaped plagioclase, followed, in order of abundance, by potassium feldspar, quartz, hornblende, biotite, and apatite. The quartz commonly appears as rectangular phenocrysts with rounded corners. In three specimens examined by R. D. Allen, the groundmass (index of refraction 1.53) is too fine grained for rapid determination and is highly altered to hematite and sericite; the principal phenocryst mineral is oligoclase in two specimens and andesine in the third.

The quartz latite porphyry is probably the same as the monzonite porphyry of Gardner's map (1940, pl. 2), called a quartz porphyry in his text (p. 274-275).

Quartz latite porphyry has intruded andesite in the northern Bullion Mountains and has supplied fragments for a landslide breccia in the sequence of gravels and volcanic rocks (Tpg) near Pacific Mesa (pl. 1). In the northwestern Bullion Mountains the quartz latite porphyry is intricately mixed with andesite (Ta), and hence the details of their relationship were not determined. But in the northeastern part of the range, just east of Pacific Mesa, quartz latite porphyry is clearly intrusive into an andesite that is believed to be equivalent to, but which is more coarsely porphyritic than the typical andesites of the northern Bullion Mountains. Hence, the quartz latite porphyry is later than the andesites and earlier than the landslide breccia in the upper part of the gravels and volcanic rocks (Tpg) exposed at Pacific Mesa.

Gravel and volcanic rocks (Tpg)

This unit of folded sedimentary and volcanic rocks and the two rock units that unconformably overlie it occur only in the vicinity of Pacific Mesa (fig. 1). The beds of this unit occur in a tilted section with an anticline near the western edge of the outcrop area and a very shallow syncline near the eastern edge adjacent to a northwest-trending fault. The relationship of this unit to the pyroclastic rocks and basalt (Tp) of the rest of the northern Bullion Mountains is not directly known because no mutual contacts are exposed. However, the presence of andesite boulders in the basal gravels of this unit indicates quite clearly that it was deposited later than the andesite flows (Ta).

Of a total exposed thickness of abut 2,800 feet for this unit, the basal 1,300 feet is gravels; the next 500 feet is andesitic basalt, and the upper 1,000 feet is mixed lacustrine and fluvial sediments and a thick pebble tuff bed.

The following is a stratigraphic section of the gravels and volcanic rocks (Tpg) northwest of Pacific Mesa in the northern Bullion Mountains.

	Approximate thickness (in feet)
Sedimentary rocks and tuffs (QTps)	
Angular unconformity, slickensided	
L. Sandstone, tuffaceous, white to buff, medium- to fine-grained, well-bedded and thinly bedded, moderately well consolioted; contains about 5 percent volcanic pebbles	25
K. Landslide breccia, composed exclusively of boulders of reddish-brown and pale-green quartz latite porphyry (Tql) with very little fine-grained matrix, bedding only faintly apparent if at all; upper 20 feet predominantly of pale-green altered porphyry, lower 30 feet mainly of reddish-brown porphyry; underlying beds severely disrupted, suggesting deposit was dumped onto wet, plastic sediments; thickness variable	50
. Shale and sandstone, tuffaceous, light-brown, light-green, and white, well-bedded and thinly bedded; some fissile shale	100
I. Grit and sandstone, coarse-grained, tuffaceous, white to light-gray, very well bedded, slabby; some cobble conglomerate interbeds containing some basalt scoria cobbles but mostly pumice fragments	100
H. Pebble tuff, dacitic, very light colored, massive and without bedding; faintly greenish and pinkish in lower part where the contained pebbles are mostly pumice and some gray vitrophyre and where interbedded with lapilli tuff; orangish-and grayish-brown in upper part where fragments in the tuff matrix are mostly red andesite and gray latite pebbles and cobbles	300
. Shale, siltstone, and tuff, white and tan, very well bedded, finer-grained at the top, coarser at the base where gradational into gravels; some paper-thin laminae; some limestone nodules	300
. Gravels and sandstone, light-gray and tan, well-bedded clasts predominantly andesite and other volcanic rocks, no basalt or granitic rocks	200
. Andesitic basalt, dark-gray with a few reddish bands and greenish areas where alteration is particularly intense; massive, equigranular, fine-grained phanerite without scoria or amygdules except at the base and top; at some places much flowage structure and finely flow-banded	500
. Gravel, red, coarse boulders; color probably due in part to stain from overlying basalt	175
. Gravel, blue-gray, coarse boulders of green and red andesite porphyry, latitic lavas, and some felsites; no granitic or basaltic material	500
. Gravel and sand, ochre; iron-stained, finer-grained gravel	50
. Gravel brown and gray, coarse boulders, predominantly andesitic lavas; no granitic or basaltic material	500+
ase of section not exposed	
Total	2,800+

Aside from a few color changes in the lower gravel deposits, their only distinctive characteristic is the absence of either basaltic or granitic material, and the overwhelming abundance of andesitic boulders.

The andesitic basalt (unit E) is so badly weathered that its accurate petrographic identity could not be established. R. D. Allen inspected some of the rock microscopically and suggested that it was probably a basaltic ndesite; he observed andesine and augite in a groundmass vith an index of about 1.54. Although this may mean it s more like an andesite than a basalt in composition, it more closely resembles the basalts of the area in field appearance.

The dacitic pebble tuff (unit H) is a brightly colored nit, particularly striking both in outcrop and on aerial photographs. It is not a truly pyroclastic rock, but probably is water laid at least in part, judging from the clastic nature of some of the finer grained beds and the presence of rounded andesite pebbles throughout most of the upper part.

The landslide breccia near the top (unit K) thickens eastward from a thin wedge beneath the north center of Pacific Mesa to a little more than 50 feet at a distance of about a quarter of a mile east where it is truncated by a large fault. Steep-sloped hills of andesite and quartz latite porphyry lie east of the fault and were probably the source of the landslide material. The low rate of taper of the breccia layer suggests that the deposit is a landslide rather than talus; talus presumably would taper more rapidly and be closer to a source slope. The shale underlying the breccia has been squeezed up as much as 10 feet into cracks and gaps in the breccia, suggesting that the breccia was dumped onto the clays and sands when they were still wet and plastic.

The top four units of this sequence (units I, J, K, and L) have been truncated completely or in part by the angular unconformity at the base of the overlying sequence (QTps). This unconformity, which is slickensided and probably sustained some thrust movement, cuts stratigraphically lower beds westward. The unconformity apparently extends beneath all of Pacific Mesa.

Sedimentary rocks and tuffs (QTps)

Sedimentary rocks and tuffs form a sequence of beds that lies in angular unconformity across the section of gravels and volcanic rocks (Tpg) exposed at Pacific Mesa. The sequence has a basal conglomerate over which lie tuffaceous and well-bedded fluvial and lacustrine deposits, and one pumice tuff. Maximum thickness of the section, exposed at the north end of Pacific Mesa, is somewhat less than 400 feet, but southward it either thins or is partly cut out by the probable unconformity at the base of the overlying rhyolite tuffs. The unit is scarcely 100 feet thick at the south end of Pacific Mesa where it is represented solely by the basal cobble conglomerate.

The angular unconformity on which this unit lies has sustained some nearly horizontal thrust movement, as indicated by the slickensides exposed on the bottom of overhanging outcrops of the basal cobble conglomerate. The strike of these slickensides is N. 75° W.

Following is a stratigraphic section of these sedimentary rocks and tuffs (QTps) exposed in the north slope of Pacific Mesa. (See page 20.)

Rhyolite tuff (QTpr)

Pacific Mesa is capped by a rhyolite tuff that can be divided into three parts according to differences in color, degree of alteration, and content of nonrhyolitic material. The contact is abrupt between the unaltered top

	Approximate thickness (in feet)
Rhyolite tuffs (QTpr)	
D. Sandstone, gray, fine-grained to very coarse grained, arkosic;	
E. Limestone, sandy, white, well-bedded in irregular slabs	2
Minor unconformity	
Probable angular unconformity	
I. Sandstone, tuffaceous, light-gray or tan, very coarse grained at top, medium-grained at base, well-bedded and generally thinly bedded; interbeds of shale or claystone with desiccation cracks; beds of nonindurated powdery clay; thin layers of pebble conglomerate	100
H. Pumice tuff, light pinkish-brown, coarse-grained alternating with fine-grained, contains fragments of pumice and pebbles of lava (5 percent of rock), well-bedded but in massive beds several feet thick; green, crumbly, chalcedonized or opalized layers form top and bottom	15
G. Sandstone, tuffaceous, very pale orange to brown, medium-grained, thinly bedded; with some pumice and volcanic pebbles	30
F. Cobble conglomerate, gray, poorly sorted, poorly cemented, densely packed; cobbles of red and purple andesite	80
60 percent quartz grains, volcanic grit interbeds	25
C. Clay-shale, silty and tuffaceous, very pale orange, slightly saline; some paper-thin laminae	10
B. Sandstone, gray, coarse- to very coarse-grained; with about 3 percent volcanic pebbles	25
A. Cobble conglomerate, gray in general aspect, mottled gray and red in closer appearance, range from pebbles to boulders, cobbles are mostly volcanic (gray and red andesite and latite flow breccia, and red andesite porphyry and quartz latite porphyry), also many plutonic boulders; deposit very well indurated at base	100
Angular unconformity, slickensided	
Gravels and volcanic rocks (Tpg)	
Total	387

part and the middle part, whose groundmass is completely altered, and less abrupt between the middle and lower parts. The most striking aspect of these rhyolite tuffs is the presence in all of them of phenocrysts of opalescent blue sanidine (moonstone) that has a distinctive blue internal reflection. These phenocrysts are generally rectangular or cubic and about 2 millimeters long.

Silicification on weathered surfaces extends several inches into the normally porous rock, forming an extremely hard, dense, and vitreous rind that looks like rhyolite flow rock or welded tuff. The slabs and boulders of rhyolite tuff having silicified rinds are resistant to further surface weathering and hence have developed a deeply colored desert varnish.

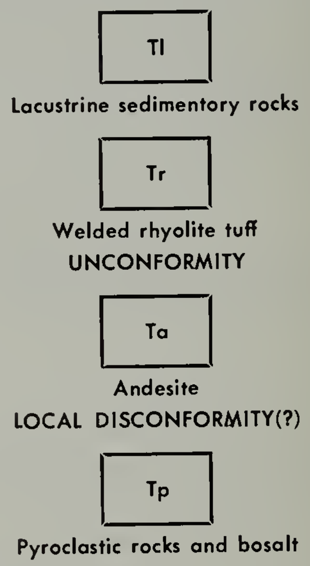
The nearly flat surface of Pacific Mesa shows little erosion. Although no deposit of rock or alluvium lies on top of the rhyolite tuffs, and there may never have been one there, a few large basalt boulders, also heavily varnished, occur on top of the mesa. The thickness of the cliff-forming top unit ranges from about 25 feet to a maximum of 50 feet.

Following is a stratigraphic section of the rhyolite tuff (QTpr) in the north slope of Pacific Mesa, northern Bullion Mountains.

	Approximate thickness (in feet)
Rhyolite tuff, lavender-gray, porous, with angular pumiceous fragments and phenocrysts of opalescent blue sanidine, clear albite, and sparse biotite and hornblende, in a groundmass that contains quartz, cristobalite, and orthoclase. No foreign volcanic pebbles. Rock is silicified on weathered surfaces	30
Rhyolite tuff, pinkish or salmon, porous, with a few volcanic pebbles (generally andesite), 5 percent angular pumice fragments of ½ to 1 inch size, and unaltered phenocrysts of opalescent blue sanidine, clear albite, and sparse biotite and hornblende, in a groundmass completely altered to ochreous claylike material	15
Rhyolite tuff, sandy, light-brown or grayish-orange, contains medium-grained sand, volcanic pebbles and fragments, and phenocrysts of blue opalescent sanidine; looks like a tuffaceous sandstone, but is probably a volcanic tuff	30
Total	75
Probable angular unconformity	
Sedimentary rocks and tuffs (QTps)	

Rocks of the southeastern Cady Mountains

The older Cenozoic rocks in the southeastern Cady Mountains differ from those of the rest of the Cady Mountains and are separated from them by pre-Cenozoic rocks and alluvium. Durrell (1953a) made a reconnaissance of the geology of the southeastern Cady Mountains while mapping the celestite deposits along the southern edge of the range, and his data have been used, with only slight modifications, in the present report. The stratigraphic relationship of the units is indicated below.



Pyroclastic rocks and basalt (Tp)

The basal unit of pyroclastic rocks and interbedded basalt flows rests directly on pre-Cenozoic crystalline rocks. Durrell (1953a, p. 38) refers to this as the "basal" unit; the present authors correlate it with the pyroclastic rocks and basalt of the northern Bullion Mountains where basalt is somewhat less abundant.

General aspects of the lithology of this unit have been discussed in the section on the northern Bullion Mountains. Durrell (1953a, p. 38) described the unit in detail and estimated the thickness to be "at least 1,000 feet and perhaps as much as several thousand feet."

Andesite (Ta)

Andesite flows overlie the pyroclastic rocks and basalt unit (Tp) apparently with conformity, though possibly with local disconformity. These andesites are correlated with the andesites of the northern Bullion Mountains. The variations in lithology are described in detail by Durrell (1953a, p. 38), who gives a thickness of about 600 feet for the unit near the celestite deposits but believes it must be several times that thick in the eastern part of the area. The description given of the andesite (Ta) in the northern Bullion Mountains includes this andesite.

Welded rhyolite tuff (Tr)

A welded rhyolite tuff about 200 feet thick unconformably overlies the andesite at the western and southern margins of the southeastern Cady Mountains. Durrell (1953a, p. 38) describes the tuff as "an obscurely bedded rock that contains abundant crystals of quartz and of brilliantly iridescent sanidine. Clastic structure is nearly always evident, but where the tuff has been vitrified, the rock closely resembles a flow." Durrell (1953a, p. 40) reports that the welded rhyolite tuff rests conformably on 50 to 200 feet of coarse, poorly sorted volcanic boulder conglomerate with a few thin tuffaceous pebbly sand beds.

This welded rhyolite tuff may be equivalent to the rhyolite tuff (QTpr) of Pacific Mesa, but such correlation was not satisfactorily demonstrated.

A small outcrop of lavender, finely flow banded rhyolite, possibly correlative with this welded rhyolite tuff, occurs just north of U. S. Highway 66, opposite the basalt flow surrounding Pisgah Crater. It lies unconformably on basalt (QTub) that may be a member of the pyroclastic rocks and basalt unit (Tp), as suggested by Durrell (1953a, p. 38), or equivalent to the later undifferentiated basalt that lies on the andesite in the hills south of Ludlow.

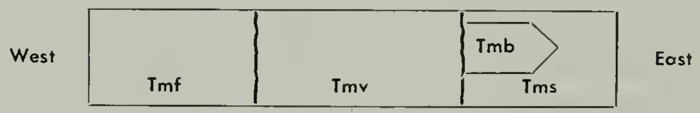
Lacustrine sedimentary rocks (Tl)

Lacustrine sedimentary rocks (Tl) containing celestite deposits conformably overlie the rhyolite tuff along the southern edge of the range and have a maximum exposed thickness of 700 feet. Durrell (1953a, p. 38, 40, 42-44) has recorded in great detail the lithology of several sections across these beds and describes them in general as follows:

> "At the celestite deposits the sediments are greenish-yellow clay, gray tuff, and gray limestone. Coarse clastic sediments are lacking * * *. Farther north and extending across the summit region of the range there is, preserved in the trough of a syncline, a sequence of coarse unconsolidated gravel composed of fragments of the underlying andesitic rocks and the welded tuff. The gravel is probably equivalent to the lacustrine sediments at the celestite deposits. [The two are included in the same map unit (Tl) of plate 1 of this report.] It overlaps the welded tuff and rests in part on the andesite. Probably it is a shore facies, or perhaps a fluviatile gravel of the same age as the lacustrine sediments * * *. From 10 to 30 percent of the beds of the unit have been replaced by dark red, green, yellow, brown, and variegated chalcedony * * * in sheets an inch to 2 feet thick."

Rocks of the northern Cady Mountains

Rocks of known Miocene age occur in the northeastern Cady Mountains where vertebrate fossils have been found in nearly flat-lying sedimentary rocks. These sedimentary rocks (Tms), with interbedded basalt (Tmb), grade southwestward through sandstones and coarse volcanic conglomerates to very coarse volcanic breccias and agglomerates (Tmv), which still farther westward and southwestward grade into mafic and intermediate lava flows (Tmf) that extend across the range. These units are all considered to be of approximately equivalent age. Schematically, the relationship between them may be shown as follows:



Tms—Sedimentary rocks; fossiliferous tuffaceous sandstone, coarser facies north and west of fossil locality, pumiceous and tuff facies south

Tmb—Basalt, interbedded with the sedimentary rocks.

Tmv—Volcanic conglomerates and breccias

Tmf—Flows, mafic and intermediate in composition

The facies that can be correlated with the fossil beds are restricted to the northern Cady Mountains (fig. 1), specifically between the Manix fault zone, the Cady fault zone, and alluvium; nowhere can they be correlated directly with other older Cenozoic rocks of the mapped area. This is particularly unfortunate as they are the only dated Tertiary rocks in the southeastern Mojave Desert.

Wherever their base was observed, these rocks were found to lie on pre-Tertiary metavolcanic, metasedimentary, or plutonic rocks. They are overlain by later gravels or by undifferentiated basalt (QTub).

Sedimentary rocks (Tms)

The fossil-bearing sedimentary rocks differ markedly within the short distance between the two fossil sites. At the northern fossil locality (KD-1, pl. 1) the strata are light olive-green, pale greenish-white, and white, well-bedded, fine- to medium-grained tuffaceous siltstone with interbedded sandstone and clay. At the other fossil locality (KD-2, pl. 1), about 2 miles south, the fossils occur in a light-brown, poorly bedded, medium- to coarse-grained silty sandstone with lenses of gravel 1 to 4 feet thick. All of these sediments are tuffaceous. About midway between the two fossil localities, these beds are cut by a short rhyolite dike a few feet thick.

Following is a composite stratigraphic section of the rock (Tms) exposed in the vicinity of the fossil localities:

	Approximate thickness (in feet)
Pediment gravel (QTh)	
Angular unconformity	
E. Rocks containing vertebrate fossil remains. Near KD-1 (pl. 1): Fine- to medium-grained tuffaceous siltstone, with interbedded sandstone and clay; greener and more sandy at base, pale-brownish and more clayey at top	50–100
Near KD-2 (pl. 1): Medium- to coarse-grained silty sandstone with gravel lenses; pale- to medium-brown	200–400
D. Tuff, poorly consolidated; white, with pinkish cast	10– 15
C. Basalt (Tmb)	50–100
B. Sandstone, red, baked	2– 5
A. Blue-gray, well-bedded tuffaceous sandstone with layers of siltstone and layers of well-rounded volcanic cobble conglomerate, topmost beds well-sorted sands that contain numerous calcite-cemented sandstone concretions half an inch in diameter	100+
Base concealed	

The correlative sedimentary rocks in the south wall of Afton Canyon, about 4 miles northwest of the fossil localities, are generally coarser grained and less tuffaceous, consisting mostly of coarse sandstone, gravel, and cobble conglomerate, but also of siltstone and poorly indurated shale. These beds appear to be thicker than in the fossil area, and are much folded and faulted. Near the base of the section in Afton Canyon, a very fine grained, pinkish-white dolomite bed about 50 feet thick is separated from the basement biotite schist by about 10 feet of coarse red gravel. The bed has been worked for magnesite (Hewett and others, 1936, p. 117-118). Above this the sandstone, conglomerate, and other rocks are brightly colored in hues of red, orange, yellow, purple, white and green. Interbedded with them near the top of the canyon wall is the same basalt flow (Tmb) as at the fossil sites. The thickness of the section in Afton Canyon was not accurately measured, but probably exceeds 500 feet.

Southwestward from the fossil area, the sedimentary facies (Tms) becomes increasingly coarse grained, grading through sandstone and cobble conglomerate into the very coarse volcanic conglomerate and breccia facies (Tmv).

Correlative pumiceous pyroclastic beds crop out south of the fossil localities. They consist of a pumice tuff and a pumice conglomerate, interbedded with tuff, tuffaceous sandstone, and clastic sedimentary rocks generally similar to those of the fossil beds. These beds contain poorly exposed rhyolite that may be in the form of flows, and hence contemporaneous with the pumice beds, or in the form of sills that formed at some time later than the pumice. Some of the tuff beds are a rhyolite tuff with distinctive opalescent blue sanidine phenocrysts like those in the rhyolite tuffs (QTpr) at Pacific Mesa in the northern Bullion Mountains. The southern edge of the pumice and rhyolite area is buried beneath a blanket of later gravel. The following is a stratigraphic section of part of these beds:

	Approximate thickness (in feet)
Tuff, white, coarse-grained; with biotite flakes	7
Tuff, white, coarse-grained; with volcanic pebbles	4
Conglomerate; andesitic pebbles	4
Pumice conglomerate, dark yellowish-orange; with tuffaceous sandstone matrix	10
Fault	
Siltstone, sandstone, and mudstone; dark yellowish-orange, with mafic volcanic fragments (1 percent)	25
Rhyolite, dark-gray, aphanitic groundmass with quartz phenocrysts, brecciated	20
Pumice-tuff, dark-brown; mostly tuffaceous sandstone with pebbles and cobbles of pumice	10
Purple-gray tuffaceous sandstone	100+
Total	180+

The contact between this pumiceous pyroclastic facies and the very much coarser pyroclastic rocks of the volcanic conglomerate and breccia facies (Tmv) to the west was not observed. Both are thought to be facies of the fossil beds; their relationship to each other presumably is one of gradation and approximate age equivalence.

Fossils. This unit is the only one in the area of this reconnaissance that has been definitely assigned to the Tertiary on the basis of fossils. Vertebrate remains were found at two principal localities, marked on the map (pl. 1) by the designations KD-1 and KD-2. Both localities lie along the southeast side of the alluvial valley in the northeastern Cady Mountains that drains into the Mojave River wash east of Afton Canyon.

Two specimens from locality KD-1 were collected and studied by Richard H. Tedford, University of California (Berkeley). He stated (written communication, 1954) that the remains represent a paleomerycid species and an oreodont species not older than early Miocene and not younger than late Miocene.

Additional material, principally camel bones, was collected later by L. J. P. Muffler from both localities and submitted for identification and age determination to G. E. Lewis of the U. S. Geological Survey, who reports: "I would hazard the guess that the age represents something between early Miocene and late Miocene" (written communication, February 1961).

Basalt (Tmb)

A relatively thin basalt flow (Tmb) is interbedded with the finer grained beds (Tms) in the vicinity of the fossil localities and northward to Afton Canyon. It apparently thins very gradually northward from 50 or more feet to less than 10 feet. This basalt is of dark brownish-black color on fresh surfaces and weathers reddish brown with black spots, giving it a distinctive appearance. It is usually dense being scoriaceous only at the top of the flow in some places. Optical determinations by R. D. Allen of two samples, one from Afton Canyon and the other from near the fossil localities, indicate that the rock is an andesitic basalt whose plagioclase ranges from about An$_{50}$ to An$_{55}$. No quartz or olivine was observed; the principal dark minerals are hematite, magnetite, and clinopyroxene. It is of nearly uniform composition throughout its 6 miles of exposure.

Volcanic conglomerate and breccia (Tmv)

Southwestward from the fossil localities, the sedimentary rocks (Tms) interfinger with coarse conglomerates (Tmv) in which subangular to subrounded cobbles and boulders of mafic and intermediate lava are packed tightly together with very little matrix. Farther southwestward these conglomerates give way to extremely coarse volcanic breccias and agglomerates (also Tmv) in which some of the blocks are several yards across. They all have a pyroclastic matrix and are so resistant to weathering that they characteristically stand in cliffs.

In general these very coarse pyroclastic rocks are light colored, frequently weathering green or brown, and probably range in composition from latitic to andesitic. Basalt appears to be absent. These rocks occur in an almost unstratified pile greater than 1,000 feet thick and possibly as much as 2,000 feet thick. A nearby volcanic vent is strongly suggested.

Flows (Tmf)

Still farther west and southwest from the fossil localities, the horizon at which the volcanic conglomerates and breccias are found is occupied by mafic and intermediate lava flows (Tmf). Some are light-colored, finely porphyritic lavas with small phenocrysts of plagioclase thickly distributed in a light gray-green dense matrix, with accessory biotite and hornblende but no quartz. There is a considerable range in the details of these light-colored lavas, but they are probably all latites. Others are darker and of andesitic to basaltic composition. Some of the interbeds are of dark-red and black andesitic flow breccia. Several of these lavas were examined by R. D. Allen for their general compositional type and a nearly complete range from latite to basalt was reported.

The contact between these lavas and the coarse breccias to the east was not observed, but the relationship is believed to be one of facies change.

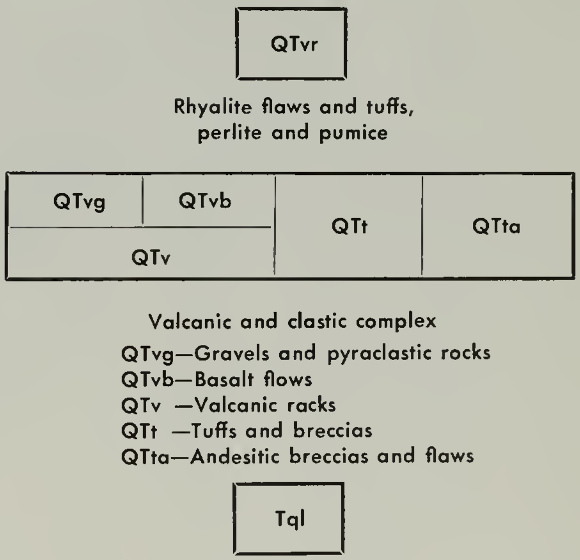
The maximum thickness of the lavas is exposed in a westward-dipping sequence that lies just north of the Cady fault zone where approximately 5,000 to 6,000 feet can be measured, presuming there is no folding or faulting which only more detailed mapping would reveal. North of this thick section, purple or dark-red andesite flowrock and pink welded flow breccia overlie Mesozoic(?) metavolcanic rocks and plutonic quartz monzonite. The dark-red andesite is radioactive as indicated by a high count on a scintillation counter, but the reason for the anomaly is not known. This andesite has a thickness of nearly 2,000 feet. In the northwestern corner of the Cady Mountains a few scattered outcrops of andesite flow breccia occur on the hills of metavolcanic rocks.

Some of the rocks mapped with the flow facies probably are intrusive. The great thickness of lavas and the extreme coarseness of the pyroclastic breccias and agglomerates strongly suggest that the north-central Cady Mountains was a center of Miocene volcanic activity or at least was very near one.

In the central part of the Cady Mountains, the Miocene lavas are overlain by basalts that have been included with the undifferentiated basalts (QTub). Some of these may be part of the Miocene lavas, but most lie in angular unconformity on the Miocene rocks. In the southwestern corner of the Cady Mountains, there are similar relatively flat-lying basalts in angular unconformity on more steeply dipping andesite flows and red and black andesitic flow breccias, mapped as undifferentiated volcanic rocks (QTuv).

Rocks of the Bristol and Old Dad Mountains

A complex suite of volcanic and clastic rocks, difficult to correlate, and separated by numerous unconformities, occupies all but the northwestern and southeastern ends of the Bristol Mountains, and all but the southern tip of the Old Dad Mountains (fig. 1, and pl. 1). These rocks appear to have been deposited in several local basins, each with a somewhat different history. Certain tentative generalizations about the stratigraphic sequence and the types of rock can be made, but they may not be verified by detailed mapping. The following diagrammatic representation of the older Cenozoic units in these ranges gives what little was deciphered of their stratigraphic relationships.

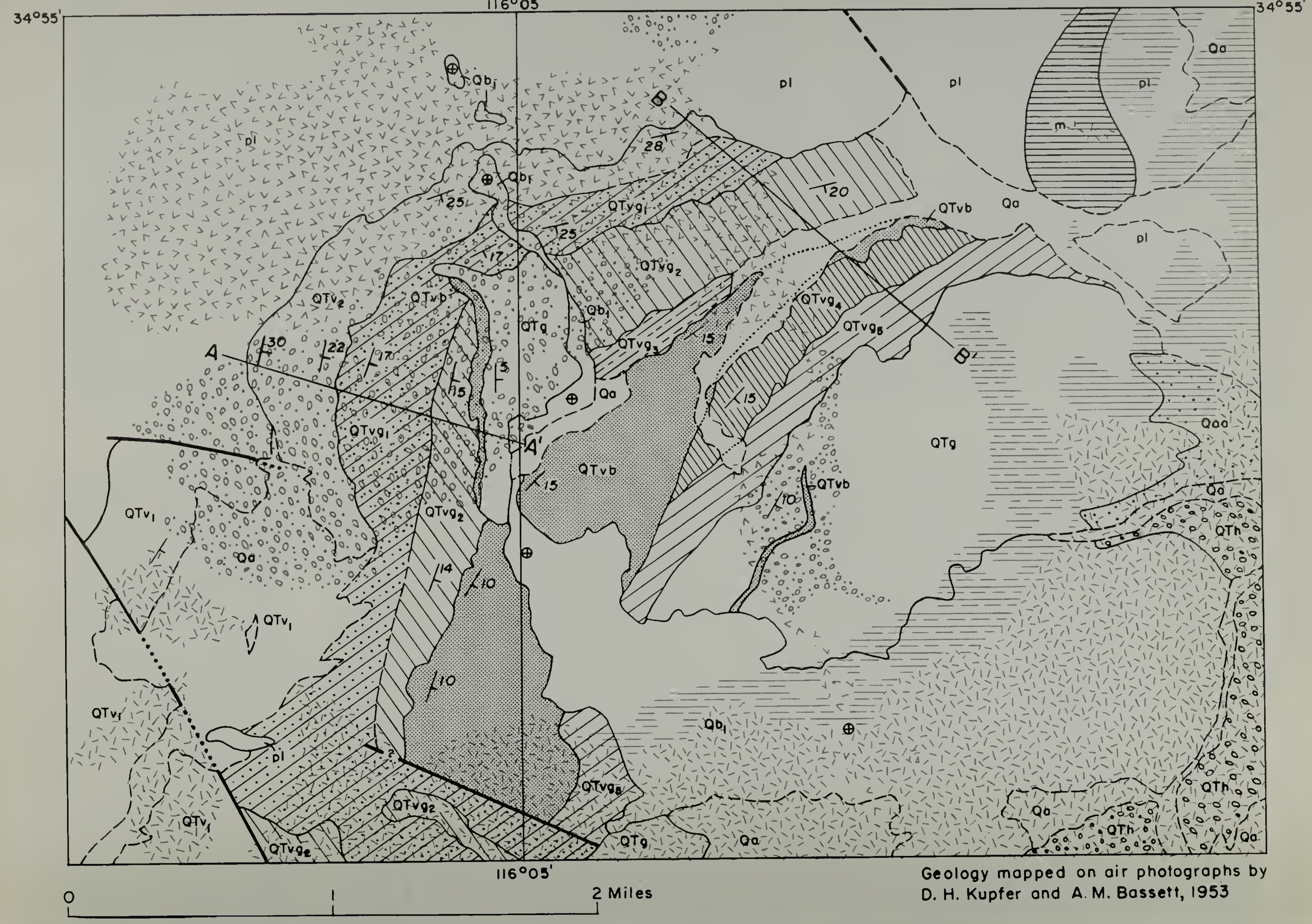


Rhyalite flows and tuffs, perlite and pumice

Volcanic and clastic complex
QTvg—Gravels and pyroclastic rocks
QTvb—Basalt flows
QTv —Volcanic rocks
QTt —Tuffs and breccias
QTta—Andesitic breccias and flows

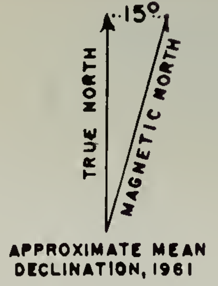
Quartz latite porphyry
(intrusive)

Undifferentiated volcanic rocks (QTuv) may include any or all of the volcanic and clastic complex and probably also some quartz latite porphyry.



Geology mapped on air photographs by
D. H. Kupfer and A. M. Bassett, 1953

EXPLANATION



QUATERNARY

YOUNGER CENOZOIC

Qa
Alluvium

Qoa
Older alluvium

Qb1
Basalt

TERTIARY OR QUATERNARY

QTh
High gravels

ANGULAR UNCONFORMITY

QTg
Tilted gravels with clasts of rhyolite tuff; interbedded thin basalt

LOCAL ANGULAR UNCONFORMITY

OLDER CENOZOIC

QTvg5
Massive pink tuff and tuffaceous sandstone with pebbles and boulders of volcanic and granitic rocks

QTvg4
Volcanic conglomerate

QTvb
Basalt

QTvg3
Light gray tuffaceous sandstone with volcanic and granitic pebbles

QTvg2
White granitic gravels, some volcanic clasts

QTvg1
Green volcanic gravels, some granitic clasts

QTv2
Andesitic agglomerates and breccias, lapilli tuffs and tuffaceous sandstones, volcanic conglomerates and boulder beds; no granitic clasts; basal arkose beds

PROBABLE UNCONFORMITY

QTv1
Undifferentiated volcanic rocks, principally welded andesite flow breccias, tuffs, and basalt

UNCONFORMITY

PRE-CENOZOIC

PRE-TERTIARY

pl
Plutontic quartz monzonite

m
Metamorphic rocks

——— — — — ……
Contact
Dashed where approximately located or inferred, dotted where concealed

——— — — ? • • • • •
Fault
Dashed where indefinite, queried where questionable, and dotted where concealed

┬15
Strike and dip of beds

⊕
Horizontal flow

A ——— A′
Location of stratigraphic section described in text

Figure 4. Geologic sketch map of Broadwell Mesa, northern Bristol Mountains.

Two areas of intrusive quartz latite porphyry (Tql) were mapped in the central Bristol Mountains, but there are probably additional outcrops that were not distinguished from the undifferentiated volcanic rocks (QTuv) that surround them.

The most nearly complete record of Cenozoic deposition within the two mountain ranges is exposed in the vicinity of Broadwell Mesa, a wide, flat area in the north-central Bristol Mountains that is capped by a Quaternary basalt flow (fig. 1). The stratigraphic section there is composed of a lower dominantly volcanic sequence (QTv), and an upper dominantly clastic sequence (QTvg) with interbedded basalt (QTvb). This area was mapped in greater detail (fig. 4) and two stratigraphic sections were measured: section A-A through the thickest part of the lower sequence, and section B-B through the thickest part of the upper sequence, though each section includes part of both sequences. Elsewhere in the Bristol Mountains these rocks occur in less complete sections and include, in addition, andesite and basaltic andesite flows (QTv) in the lower part of the section, and are overlain by rhyolite flows and tuffs (QTvr).

In the Old Dad Mountains and adjacent parts of the Bristol Mountains there are similarly diverse types of volcanic and clastic rocks whose stratigraphic sequence was not worked out. The lower part of the section consists of two apparently contemporaneous units: (1) coarse volcanic conglomerates that grade into tuffs which are overlain by tuffaceous sandstones, tuffs, agglomerates, and breccias (all mapped as QTt), and (2) andesitic breccias and flows (QTta). These are overlain by rhyolite flows, tuffs, perlite, and pumice (QTvr), and in the Old Dad Mountains by lava caps (QTuv) of basalt, andesite, and perhaps other types of flows; the lava caps were not individually inspected and may in part be gravel deposits.

The sequence in the northern and western Bristol Mountains, for which QTv, QTvg, and QTvb symbols are used, and the sequence in the Old Dad and adjacent parts of the Bristol Mountains, for which QTt and QTta symbols are used, are probably equivalent in age but have extensive facies changes between them. Although both sequences occur in the central Bristol Mountains, the details and correlations of the profusion of volcanic rock types were not understood during this rapid reconnaissance; hence most of the rocks there are shown as undifferentiated volcanic rocks (QTuv).

Near the northern part of the central Bristol Mountains several outcrops of limestone 20 to 50 feet thick have been mined as onyx. The limestone is banded, multicolored, and in part botryoidal; thus, it appears markedly different from the limestones of pre-Tertiary age. They may be spring deposits of Cenozoic age but their relationship to the surrounding rocks was difficult to interpret on so brief an inspection.

Volcanic rocks (QTv)

A relatively complete section of the volcanic rocks (QTv) exposed in the Bristol Mountains crops out in the northern part of the range in the vicinity of Broadwell Mesa. In stratigraphic section A-A (fig. 4), only the upper part of this section is included. It is designated on figure 4 as QTv-2 and consists of about 530 feet of andesitic agglomerate and breccia, tuff, tuffaceous sandstone, volcanic conglomerate, and a basal arkose bed that rests on decomposed and deeply weathered plutonic quartz monzonite. The contact with overlying unit (QTvg-1) is gradational, and the distinction between them is based principally on the greater induration of the lower unit and the preponderance in it of volcanic over clastic layers. The lower part of the volcanic rock section (QTv-1) crops out south of the measured section A-A, and is separated from it by a west-trending fault. It is composed of a welded andesite flow breccia, tuff, and basalt.

Stratigraphic section A-A.
(Thicknesses calculated from Brunton-pace traverse; symbols refer to map units on figure 4)

	Approximate thickness (in feet)
Map unit Qb_1	
Basalt, vesicular, fresh olivine phenocrysts. Horizontal	5
Unconformity	
Map unit QTg	
Granitic gravels. Coarse gravels and sands; contain rhyolite fragments; includes a 1-foot thick pod of pure glass shards; very coarse basalt rubble at base, possibly a flow. Dips 5° to 10°	100
Angular unconformity	
Map unit QTvg-2 (total thickness 195 feet)	
Sand, medium to coarse, some silt and conglomerate lenses, well-bedded, thin-bedded	30
Poorly bedded granitic sand and gravel	65
White tuff, some layers with granitic and metamorphic boulders, top 1 foot a pure white tuff	10
Granitic sands and conglomerate, nontuffaceous	60
Tuffaceous sandstone, white, predominantly granitic fragments, some volcanic; poorly consolidated; greenish beds near base. Dips 15°	100
Map unit QTvg-1	
Volcanic gravel and tuffaceous sandstone, green, some granitic fragments. well-bedded, moderately well consolidated; local pebble and cobble layers; a lag gravel of huge boulders (up to 20 feet across) of basalt and other volcanic rocks at base of unit rests on a dip slope forming a conspicuous black hogback. Dips 17°	100
Map unit QTv-2 (total thickness 530 feet)	
Lavender-white pebbly tuff; tuff at base with increasing pebble content upward. (Top concealed by lag gravel)	40
Green, densely packed conglomerate of andesitic lava in green tuffaceous matrix; at top conglomerate of uniform sized cobbles with little matrix (15 feet); at center pebble conglomerate, grades to tuff, lighter green (20 feet); at base pebble and cobble conglomerates, uniform sized fragments with little matrix (25 feet)	60
Green lapilli tuff and clay, some volcanic pebbles and cobbles; lithic and crystal tuff with biotite, hornblende, and quartz phenocrysts; coarse sand	50
White, coarse pyroclastic layer with biotite, quartz and hornblende crystals; some well-bedded and tuffaceous sandstone	10

	Approximate thickness (in feet)
Lenticular, green, pebble to boulder andesitic agglomerate; bright-green matrix; thickens to north	10
Light-buff to green tuffaceous pebble to cobble breccia	30
Flow breccia of dark brown-weathering lava boulders in bright-green hornblende crystal tuff matrix, very lenticular. Dips 22°	60
Massive, pink, apanitic lava breccia, brown in outcrop	30
Buff sandstone with pebbles at base	17
Gray to green, pebble to cobble andesitic breccia: at top bright-green, well-bedded andesitic cobble breccia (50 feet); at center gray to brown volcanic breccia; angular to subangular andesitic cobbles in nontuffaceous groundmass of feldspar and quartz sand grains (40 feet); at base marker bed flow breccia, varies from tuffaceous sandstone to pebble breccia; caps cliff (3 feet)	93
Greenish-gray cobble agglomerate or conglomerate, subrounded cobbles and boulders of pumice and volcanic rock in greenish-gray tuffaceous matrix; some white sandstone. Gradational from unit below	60
Green, very coarse grained tuffaceous sandstone: at top very coarse grained sandstone, grades to unit above (15 feet); at center green, very coarse grained sandstone with red andesitic granules; whiter and more tuffaceous near top (10 feet) at base white tuffaceous sandstone, thin-bedded and well-bedded; some volcanic pebbles near top; unit transitional from arkosic below to volcanic above (25 feet)	50
Arkose, dips 30° E.: at top granitic sand, some pebbles and cobbles, white to light-gray in color; a few pink andesite fragments (10 feet); at center red and white layers of fine-grained sandstone (3 feet); at base orange arkosic soil and gravels, some conglomerate (7 feet)	20
Total thickness	1,000
Unconformity	
Map unit pl.	
Quartz monzonite porphyry, decomposed at surface, weathered to a depth of about 50 feet	

Elsewhere in the Bristol Mountains, the volcanic unit (QTv) consists mainly of andesitic flow breccia and andesitic to basaltic lava. These lava flows range from andesite through basaltic andesite to olivine basalt, apparently changing composition in this order with decreasing age, though this was not determined conclusively. The lava flows near the base of the sequence are generally massive andesites that contain phenocrysts of augite and andesine. A number of samples examined by R. D. Allen are hypersthene andesites with variable amounts of volcanic glass of index 1.52. Samples of lavas somewhat higher in the section contain plagioclase of composition An_{50} and one or more of the following accessory minerals: augite, hypersthene, olivine and magnetite. Lavas near the top of this unit are olivine basalts.

In a sample of dacitic volcanic breccia from the base of the sequence in the southwest corner of the Bristol Mountains, R. D. Allen found the fragments to be porphyritic dacite with a glass of index 1.50. The phenocrysts are of andesine, quartz, biotite, and amphibole.

Gravel and pyroclastic rocks (QTvg)

The upper part of the section at Broadwell Mesa has been mapped as a separate unit (QTvg) because it contains more clastic rocks and fewer volcanic rocks than the lower part, and the fragments are largely of granitic material. It apparently rests conformably on the volcanic rocks (QTv-2) that form the lower part and is gradational with them. A thickness of 1,450 feet of gravel and pyroclastic rocks (QTvg) was measured (section B-B) not including the interbedded unit of basalt (QTvb).

Stratigraphic section B-B.
(Thicknesses calculated from Brunton-pace traverse, symbols refer to map units on figure 4)

	Approximate thickness (in feet)
Map unit QTg	
Granitic and volcanic cobble gravels, some boulders. Dips 0°-10°	100+
Minor unconformity	
Map unit QTvg-5	
Massive pink tuff, with 15 percent volcanic pebbles principally pumice; vague bedding. Dips 10°-15°	200
Map unit QTvg-4	
Conglomerate, pebbles and cobbles (20 to 50 percent) in tuffaceous sandstone matrix; locally well bedded. Dips 15°-17°: at top volcanic pebbles (60 feet); at center granitic and gneissic pebbles and cobbles (75 feet); at base granitic and volcanic pebbles? (concealed) (115 feet)	250
Minor unconformity	
Map unit QTvb	
Altered basalt, thickens rapidly southwestward. Dips 15°	80
Map unit QTvg-3	
Light gray tuffaceous sandstone with volcanic pebbles, cobbles and boulders, some granitic; mostly concealed	100
Map unit QTvg-2	
Granitic boulder gravels, no volcanic fragments	500
Map unit QTvg-1	
Light-gray and green conglomerates and tuffaceous sandstones with granitic fragments dominant near top and volcanic fragments nearly exclusive near bottom; many beds of tightly packed volcanic cobbles of uniform 2 to 3 inch size with little matrix. Dips 25°	400
Map unit QTv-2	
Dark-green andesitic flow breccias and volcanic conglomerates; dark-gray vitreous or flinty sandstone layers; noticeably more indurated than overlying units. Dips 25°-28°	250
Coarse arkose and white tuffaceous sandstone, some granitic pebbles	50
Unconformity	
Map unit pl	
Plutonic quartz monzonite porphyry	
Total thickness	1,930+

The basal 50 feet of unit QTvg-1 is a volcanic gravel with enormous boulders of basalt and andesite, many of which exceed 10 feet in diameter. The green volcanic gravels above it contain a gradually increasing percentage of granitic fragments up-section, and grade upward into beds of predominantly granitic material (QTvg-2) as the color changes to white. The uppermost member of this unit, a pink tuff and tuffaceous sandstone (QTvg-5), contains pebbles and cobbles of pumice that may be related to the rhyolite and rhyolite tuff with associated pumice that are exposed farther south in the Bristol Mountains. This correlation is further suggested by the presence of fragments of rhyolite tuff with opalescent sanidine phenocrysts in the overlying gravels (QTg).

Southward from Broadwell Mesa, this unit becomes increasingly volcanic and grades into cinder breccias. In these cinder breccias, smoky colored glass is abundant and has an index of 1.50 to 1.51.

Basalt (QTvb)

The basalt unit (QTvb) that is interbedded with the gravels and pyroclastic rocks (QTvg) at Broadwell Mesa is terminated abruptly by a fault of considerable displacement at the south end of its exposure in the Broadwell Mesa section. Against this fault the thickness of the unit is nearly 1,000 feet, but it thins gradually northeastward to less than 100 feet before being covered by alluvium.

It is an olivine basalt in which much of the olivine is altered to iddingsite. It contains relatively few amygdules, which are filled with calcite, and is cut in a few places by veins of fibrous calcite. The basal 10 to 15 feet of the unit is generally a scoriaceous breccia over which the next 50 to 100 feet is slabby and nonvesicular. The remainder of the unit is composed of separate flows, as much as 100 feet thick, of dense, massive olivine basalt with minute plagioclase laths and relatively few vesicular layers.

Elsewhere in the Bristol Mountains this unit includes altered basalts that lie above volcanic or granitic gravels and are overlain directly by rhyolite flows and tuffs (QTvr). At the east end of the hills south of Ludlow, the basalt rests unconformably on the andesites (Ta) and the pyroclastic rocks and basalt unit (Tp) of the northern Bullion Mountains; it may be equivalent to the undifferentiated basalt (QTub) that forms a cap unconformably across the same rocks (Ta and Tp) at the other end of the hills.

Tuffs and breccias (QTt)

The lithology of the volcanic tuffs and breccias of the Old Dad and southern Bristol Mountains is best described by discussing several of the observed occurrences of the unit. No regional stratigraphic sequence was worked out.

Outcrops of a basal member that ranges from volcanic conglomerate to lapilli tuff are scattered throughout the Old Dad Mountains. The conglomerates are generally well bedded and consist of 10 to 50 percent volcanic fragments in a coarse-grained tuffaceous sandstone. Most of the fragments are in the pebble-size range, but there are boulders a foot or more in diameter. Generally these conglomerate beds are tilted and at several localities are overlain unconformably by younger rocks. Sections of the conglomerate in at least two places are estimated to be greater than 1,000 feet thick. In the central and northern part of the Old Dad Mountains, these basal rocks are overlain by well-bedded pyroclastic rocks over 300 feet thick. The individual layers are as much as 50 feet thick and are composed of tuffaceous sandstone, tuff, agglomerate, and other volcanic materials. They in turn, are capped by flat-lying volcanic flows (QTuv) that may have a variable composition but seem to be mostly andesite or basaltic andesite; two samples examined by R. D. Allen contained about 20 to 25 percent phenocrysts of hornblende, plagioclase (near An_{50}), and quartz in a groundmass of plagioclase laths, crystallites, hematite, and volcanic glass with an index less than 1.50.

In the northwestern Old Dad Mountains, the basal member is tuffaceous, includes a red arkose, 5 to 20 feet thick at the base, and grades upward into andesitic agglomerates, breccias, and possibly flows (QTta). South of this are well-bedded and thin-bedded tuffaceous sandstones, tuffs, agglomerates, and breccias that are complexly disrupted by relatively minor faults.

At the southwestern corner of the Bristol Mountains, a complex section of steeply dipping volcanic rocks unconformably overlain by basalts and gravels is in the area of tuffs and breccias (QTt) and andesitic breccias and flows (QTta). It includes well-bedded volcanic conglomerates, unbedded volcanic breccias, lava flows (of quartz latitic to andesitic composition), red cinder breccias similar to those of the western Bristol Mountains (QTvg), and a coarse-grained pumiceous agglomerate similar to some associated with rhyolites farther north. The section is much faulted, with consequent repetitions and omissions, but is probably over 1,000 feet thick.

In the central Bristol Mountains, rocks that can be correlated with both the volcanic rocks (QTv) and the tuffs and breccias (QTt) occur together, but their relationships were not worked out in the degree of detail they merit. Hence the units are designated on the map (pl. 1) as undifferentiated volcanic rocks (QTuv). The basal part of the sequence is a series of poorly sorted, vaguely bedded, pebble conglomerates or breccias tilted to a vertical position, and is about 1,000 feet thick. These beds probably are equivalent to the tuffs and breccias of the Old Dad Mountains. They are overlain unconformably by about 50 feet of moderately dipping andesite flows (either QTv or QTt), that are in turn unconformably overlain by volcanic gravels (probably QTvg), basalt (probably QTvb), and rhyolite (QTvr).

Andesitic breccias and flows (QTta)

In some parts of the Old Dad and southern Bristol Mountains, andesitic breccias and flows (QTta) have been distinguished from the tuffs and breccias (QTt). It is strictly a lithologic and not a stratigraphic distinction. The unit consists of andesitic agglomerates, cinder breccias, and andesite and basaltic andesite flows. In the northwestern Old Dad Mountains, more than 300 feet of andesitic breccias, agglomerates and possibly andesite flows (QTta) lie conformably on the tuffs (QTt).

At the northwestern end of the Marble Mountains, east of the Old Dad Mountains, this unit (QTta) also attains considerable thickness and lies on tuffaceous rocks (QTt). Hazzard (1933, p. 59-60) in his description of the rocks of the eastern Mojave Desert, was primarily concerned with the area just east of the Old Dad and Bristol Mountains. He recognized two periods of late Cenozoic rhyolitic volcanism and beneath the younger of the two he found the following:

> "Andesites, rhyolites, and agglomerates: Reddish or gray andesite with greenish, white, or gray agglomerate beds at the base. Rhyolite or latite flows locally present. In the Marble and Ship Mountains local shale and sandstone beds carrying vertebrate remains occur at the base. Maximum thickness 250 feet. Volcanic portion of the unit includes some intrusive plugs of rhyolite or latite. Estimated thickness for stratified portions of the unit, 750 feet."

This was his basal Tertiary unit and probably is equivalent in part to both the tuffs and breccias (QTt) and the andesitic breccias and flows (QTta) of the Bristol and Old Dad Mountains.

Rhyolite flows and tuffs (QTvr)

Rhyolitic rocks are distributed throughout the volcanic areas of the Bristol and Old Dad Mountains, principally as remnants that cap isolated hills. They are younger than any of the other volcanic rocks and generally flat lying.

The rhyolitic rocks occur as flows, tuffs, pumice, and perlite. The flows are either very fine grained, vitreous, gray or lavender, porphyritic rhyolite, usually structureless; or pink, finely flow-banded, aphanitic rhyolite with thin tuffaceous laminae. The rhyolite tuffs are lavender or pink and invariably have phenocrysts of distinctive opalescent blue sanidine, in which respect they resemble the rhyolite tuffs (QTpr) that cap Pacific Mesa in the northern Bullion Mountains. In these tuffs, surface silicification in some instances extends deeply into the rock making it appear as a vitreous flow, and much of what was mapped as rhyolite flows is probably rhyolite tuff with well-developed surface silicification. R. D. Allen examined four rhyolite samples that are probably mostly silicified tuffs, from widely separated parts of the Bristol and Old Dad Mountains. They contain from 5 to 15 percent phenocrysts of quartz, oligoclase, and opalescent blue sanidine. In three samples the most abundant phenocryst mineral is sanidine and in the fourth it is quartz; oligoclase is present in minor amounts; biotite was observed in two samples. All samples have fragments of glass in a devitrified groundmass of index 1.49. The sample with quartz as the principal phenocryst mineral is probably a rhyolite flow, those with opalescent sanidine and biotite are probably silicified tuffs. Some of the rhyolitic rocks may be intrusive stocks, plugs, or dikes, but none were found to be unquestionably so.

Pumice occurs most commonly in sedimentary aggregates of cobbles and pebbles of frothy pumice in pumiceous tuff. It is particularly abundant along the western edge of the Bristol Mountains where apparently it has been prospected but never worked commercially.

The perlite beds are composed of gray, vitreous, and apparently quite pure perlite that is worked commercially in the west-central Bristol Mountains. There are relatively large reserves of unworked perlite in the southern Old Dad Mountains and the east-central Bristol Mountains.

Problems of correlation of the older Cenozoic rocks

Age cannot be used as a basis for correlation in this reconnaissance area inasmuch as only one unit of the older Cenozoic rocks is dated paleontologically. Correlation on a lithologic basis is also of little use, especially when based on such rapid reconnaissance mapping, because this is an area of isolated mountain ranges composed of diverse rocks, in which there is much repetition throughout the column, and rapid facies changes through a wide variety of textural and lithologic types. Many of the units apparently were deposited in areas of limited extent, especially local volcanic flows or piles of ash and breccia that closely surrounded their vents.

The authors sought to determine whether the lavas and pyroclastic rocks might exhibit some systematic change of composition with time, but were forced to conclude that nearly the entire range of volcanic rock types occurs with virtually no regard to sequence. Basalts occur throughout the section and there seems to be no means of distinguishing with certainty between those of Tertiary age and those of Quaternary age; they exhibit all variations of weathering apparently without respect to age, and hence such factors are of very little aid in correlation. Neither are the degree of deformation and the extent of dissection reliable indicators of age; the moderately dissected, flat-lying, Miocene fossil beds (Tms) of the northern Cady Mountains, for example, are much older than the deeply dissected, tilted and folded gravels (QTg) of Afton Canyon.

There seems to be a distinct possibility, however, that the rhyolite tuffs that cap Pacific Mesa in the northern Bullion Mountains (QTpr) and those that cap hills in the Bristol and Old Dad Mountains (QTvr) were contemporaneous. Both represent the latest volcanic eruptions in their respective area, aside from Quaternary basalts; both are flat laying; both are identical in color, texture, and phenocryst minerals; and—most distinctive of all—both include opalescent blue sanidine. But lithologic correlations over such distances (20 miles) are questionable, and even such a distinctive rock type may not necessarily be restricted to one period of eruption. Nevertheless, for regional stratigraphic correlations within the mapped area, this distinctive rock type probably holds the most promise.

The welded rhyolite tuff (Tr) of the southeastern Cady Mountains, according to the description by Durrell (1953a), is not identical to the others; even though it also has "iridescent blue sanidine phenocrysts", it is neither at the top of the section nor flat lying.

Similarly, the rhyolite tuff with opalescent sanidine in the pyroclastic facies of the sediments of the northern Cady Mountains (Tms) is not at the top of the section, nor is it flat lying, but lithologically it is identical to the rhyolite tuffs QTpr and QTvr.

In order to make any headway against the problems of correlation, the principal need is for more detailed mapping of the older Cenozoic rocks, particularly at certain key areas. The relationship between the rocks of the Bristol and Old Dad Mountains and those of the northern Bullion Mountains could probably be worked out best in the southwestern Bristol Mountains and adjacent parts of the hills southeast of Ludlow. The relationship of the fossil beds of the northern Cady Mountains to the rocks of the southeastern Cady Mountains might be determined by more detailed mappings in the eastern Cady Mountains. There is no direct outcrop connection between the northern and southeastern Cady Mountains, but it seems likely that some distinctive members or sequences might be correlated across the intervening alluvium and plutonic rocks. This could answer the important question of whether the rocks of the northern Bullion Mountains are earlier, contemporaneous, or later than the Miocene fossil beds.

YOUNGER CENOZOIC DEPOSITS

The deposits of the southeastern Mojave Desert shown on the map as younger Cenozoic are of known or probable Quaternary or late Pliocene age. They include the Pleistocene(?) sediments of Twentynine Palms and the Pinto Basin, gravel deposits, playa deposits, basalt cones and flows, modern alluvium, and wind-blown sand. Only the sediments of Twentynine Palms and the Pinto Basin have yielded fossils, and these are not adequate for precise dating. Alluvial fan gravels, stream channel fill, playa deposits and wind-blown sand are being deposited at present within the area.

Gravel deposits in the area are of several ages and types; in this report they have been subdivided into four groups on a structural and physiographic basis rather than the more conventional stratigraphic basis. This was necessary because the ages of the gravels are unknown, their lithologies nearly identical, and they rarely occur in superposition. Even though this method may place some equivalent stratigraphic units in different groups, it probably gives relative ages for most units as well as a stratigraphic classification could, and is far more easily used. The four subdivisions are (1) tilted gravels (QTg) which have been tilted from their original angle of repose; (2) high gravels (QTh) that are essentially flat-lying undeformed gravels found in positions not related to present stream channels; (3) older alluvium (Qoa) that includes material of the same type and position as modern alluvium but which is now being dissected; and (4) modern alluvium (Qa) that includes all stream deposits and alluvial fan gravels being laid down in the present drainage system.

Pleistocene(?) sediments of Twentynine Palms and the Pinto Basin (QTs)

Nonvolcanic sediments of probable Pleistocene age crop out in the hills near Twentynine Palms, in Gypsum Ridge west of the Bullion Mountains, and in scattered outcrops around the basin that contains Dale Dry Lake. The distribution of outcrops suggests that the entire valley from Dale Dry Lake west to beyond Twentynine Palms and northwest along the Bullion Mountains is underlain by such Pleistocene(?) deposits.

Sediments that crop out in a small hill at the southeast corner of the Pinto Basin have been named the Pinto Formation by Scharf (1935). They are tentatively correlated with the Twentynine Palms sediments in age, though they were clearly deposited in a different basin. Interbedded with the sediments at this locality is a basalt flow (QTb) that also forms the northeasternmost tip of the Eagle Mountains south of the Pinto Basin.

Vertebrate fossils collected both in the hills near Twentynine Palms and in the Pinto Basin have been tentatively assigned to the Pleistocene, but both collections are inconclusive.

These sediments rest unconformably upon the older plutonic and metamorphic rocks and are overlain by alluvium. The beds near Twentynine Palms are broadly folded with low angles of dip except locally near faults, where dips as high as 80° have been observed. The section in the Pinto Basin has a fairly uniform dip of 30° to 40° S. and lies near the junction of two probable, but concealed, major faults, one trending northwest, the other trending east.

Lithology and stratigraphic sections. In the hills just east of Twentynine Palms, a typical section consists of coarse sands and gravels near the top and finer sands and silts below. The cobbles and boulders near the top of the section are composed of granitic and metamorphic rocks. Some of the sands and silts are essentially unconsolidated and others are cemented by carbonate. Colors range from gray to pale greenish yellow. The absence of pyroclastic and volcanic rocks is in sharp contrast to nearly all of the older Cenozoic rocks of the southeastern Mojave Desert. Some of the sandstone is tuffaceous in the outcrop 8 miles north of Twentynine Palms, perhaps because the source area lay to the north in the pyroclastic rocks of the northern Bullion Mountains (Tp). All other sections are nontuffaceous.

The most distinctive marker bed is a zone 3 to 15 feet thick of nodular-weathering, carbonate-cemented sandstone, that crops out at several places near Twentynine Palms. The "marbles" that weather from this sandstone are concretions 1 to 1½ inches in diameter and light gray or light brown in color. Whether these sandstones occur at several horizons, or if all such outcrops are of a single marker bed was not determined.

Calcium and sodium sulfate efflorescences and crusts occur in the deposit throughout its areal extent. R. D. Allen identified gypsum, anhydrite, thenardite, and aphthitalite(?) ($K_3Na(SO_4)_2$), and Noble (1931) found traces of nitrate.

These sediments attain a maximum thickness greater than 1,000 feet. F. S. Riley of the U.S. Geological Survey (oral communication, 1953) measured a section 800 feet thick in Gypsum Ridge. The following section, over 600 feet thick, is from the fossil-bearing hill at the east edge of Twentynine Palms.

	Approximate thickness (in feet)
Sand, possibly of Recent age	50
Boulder conglomerate	20
Coarse greenish sand	20
Boulder conglomerate	30
Medium sand to gravel, yellow-brown	100
Calcite-cemented nodular sandstone, weathers to "marbles" 1 to 1½ inches in diameter	10
Very fine sand and silt, greenish-gray, contains vertebrate fossils	20
Boulder gravel to sand	30
Sandstone, reddish	5
Silt and sand, yellow-orange	20
Interbedded sand and gravel	200
Very fine sand, rose-brown	10
Sandstone, fine sand, and silt	150?
Base not exposed	----
Total greater than	665

In the southeastern corner of the Pinto Basin near the Western edge of the Coxcomb Mountains, a sequence of gravels, lacustrine sediments, and basalt was first described by Scharf (1935) in conjunction with the discovery of remains of an early culture of man. Of the three localities to which he refers, only the long low ridge at the gate between the Coxcomb and Eagle Mountains was mapped and studied by the present authors who measured the following section.

	Approximate thickness (in feet)
Granitic boulder fanglomerate or talus-breccia	Over 500
Arkosic gravel	5
Basalt (QTb)	30
Arkosic gravel	10
Bedded gypsum	½
Brown clay, thin-bedded	18
Gray-green to bluish clay, locally sandy	15
Yellow-green to yellow-brown saline clay with interbedded calcareous and sandy layers	10
Arkosic, coarse sand to gravel	6
Granitic boulder gravel	100+
Total beneath top member	195+

Age and correlation. Vertebrate fossils were first found in the hill at the east edge of the town of Twentynine Palms in 1918 by Noble (1931, p. 29), but although the fragments he collected were unidentifiable he believed their probable age to be late Tertiary. More fossils were later discovered by Mr. E. Schenck and were sent to the Stanford University collection but cannot now be located. Additional specimens were collected in 1955 at the same locality by L. J. P. Muffler and sent to G. E. Lewis, of the U. S. Geological Survey, for study. Mr. Lewis states (written communication, February 1956): "The inconclusively identified fragments may represent ?*Tanupolama* sp. and ?*Odocoileus* sp. of Pleistocene age, but my opinion is that the evidence is inconclusive." However, the clastic nature of the sediments, the lack of interbedded volcanic units, the relatively mild deformation, and the general areal distribution of the sediments strengthen the probability that the rocks are of Quaternary rather than Tertiary age.

Correlation of these sediments near Twentynine Palms with any of the older Cenozoic successions cannot be established. Only the upper part of the sequence of rocks at Broadwell Mesa in the northern Bristol Mountains is in any way similar, and these might be of comparable age. The beds are probably older than the Manix Lake Beds (northwest of the Cady Mountains) of known late Pleistocene age (Howard, 1955), which are almost completely undeformed in an area fully as active tectonically as the vicinity of Twentynine Palms. The sedimentary rocks of Gypsum Ridge are considered to be part of the Twentynine Palms section. Although not shown on the map, they are eroded to expose beds near the center that could be older, perhaps of late Tertiary age (F. S. Riley, oral communication, 1953).

Vertebrate fossils were found in the correlative(?) sedimentary rocks of the Pinto Basin by Scharf (1935) who reports that "horse and camel remains found in the Pinto Formation date it as Pleistocene age", but he gives no further details on the fossils or their specific locality. Possibly these fossils were discovered in the flat-lying beds along the banks of "Pinto Wash" which are also called Pinto Formation by Scharf but which are probably of a different and later age than the tilted deposits of the small hill at the outlet of Pinto Basin. For this reason the age of the Pinto Formation must remain in question.

Tilted gravels (QTg)

This unit includes the gravel deposits that have been tilted from their original position by faulting or folding. They occur in scattered outcrops in and west of the northern Bullion Mountains and in the eastern Cady Mountains. They rest unconformably on the older Cenozoic or pre-Tertiary rocks and, where covered, are overlain by either the high gravels or by alluvium.

Their exact ages are unknown. Different outcrops may well represent ages ranging from late Tertiary to early Quaternary and perhaps many of them bridge the Pliocene and Pleistocene boundary. Much of the gravels and pyroclastic rocks (QTvg) in the Bristol Mountains and the Pleistocene(?) sediments (QTs) in Gypsum Ridge north of Twentynine Palms (pl. 1) may be comparable in age.

A typical example of a tilted gravel is the deposit of well-bedded gravels and sands in the center of the northern Bullion Mountains (pl. 1). The beds are tilted as steeply as 45° and contain both granitic and volcanic clasts. These gravels, as well as the undifferentiated basalt flow (QTub) on which they locally lie, rest on a surface of considerable relief and in marked disconformity on the older Cenozoic rocks of the northern Bullion Mountains (Tp and Ta). Yet even so, they dip at about the same angle and in the same general direction as these older units. Thus, although considerable erosion took place before the deposition of the basalt flow and gravels, the major tilting of the northern Bullion Mountains block appears to have occurred after their deposition. These gravels correlate directly with the "post Black Mountain Basalt fanglomerate" that Gardner (1940, p. 288) mapped in the Newberry and Ord Mountains just west of the northern Bullion Mountains. The following is a section of the gravels in the northern Bullion Mountains.

	Approximate thickness (in feet)
Cobble- to boulder-gravel, well-bedded and well-consolidated; cobbles are 90 percent granitic and 10 percent volcanic; no basalt cobbles observed	25
Massive sandstone, forms small cliffs that can be traced for a mile or more	5
White tuffaceous sandstone and siltstone, well-bedded; some chert	50
Total	80

The tilted gravels in the eastern Cady Mountains are moderately well-consolidated alluvial gravels composed mainly of plutonic and metamorphic fragments but with some volcanic fragments; the strata locally form conspicuous cliffs and dip 10° to 20° to the east or northeast. They overlie in angular unconformity the older Cenozoic volcanic rocks of the area.

The large area of tilted gravels north of the Cady Mountains is a hill of uplifted and folded gravel beds cut by the Manix fault, on which lie unconformably the upper Pleistocene Manix Lake Beds.

High gravels (QTh)

Gravel deposits that are not tilted, yet are high above the present alluvial level and are unrelated to the present drainage system, are mapped as high gravels (QTh). They occur as large, relatively undissected remnants within the mountain ranges and at their borders. Their distribution suggests that they were deposited by streams with an older and, in some places, very different drainage pattern from that of the modern washes. Such deposits are virtually absent in the southeastern part of the area. The high gravels are typically composed of coarse, unsorted alluvial fan material, generally poorly consolidated, and with fragments of widely differing composition.

Most of the high gravels were laid down on pediment surfaces. The gravels probably were not deposited simultaneously on a single widespread pediment surface that extended across several drainages, but rather were deposited during several periods and on different pediment surfaces that had different drainage histories. The high gravels are probably all younger than any of the older Cenozoic rocks, and older than the development of the present drainage pattern. Their ages are assumed to range from late Pliocene to Pleistocene.

Older alluvium (Qoa)

An older aluvium, related to present drainage channels but now being dissected, can be distinguished in many places from the modern alluvium. In some areas, the older alluvium is 20 feet or more above the present surface of deposition, more commonly it is only a matter of a few feet above, and in some places it is gradational with the modern alluvium. In such cases, the distinction between older alluvium and modern alluvium becomes arbitrary. Older alluvial deposits are present in all parts of the area, but they are most abundant at the base of the ranges where the alluvial fans spread out from the mountain fronts.

A particularly characteristic aspect of the deposits of older alluvium is the extensive development of desert varnish which imparts to them a dark surface that contrasts with the light color of the more freshly exposed surfaces of the modern alluvium.

The large area of older alluvium shown in the northwestern Cady Mountains represents deeply dissected gravels that grade laterally into lacustrine clays of Pleistocene Manix Lake, which has been described by Buwalda (1914) and by Blackwelder and Ellsworth (1936). The age of the Manix Lake Beds, and hence of these equivalent gravel facies, is late Pleistocene (Howard, 1955); the lake probably existed during a Wisconsin pluvial period.

Playas

In this reconnaissance the playas were studied in greater detail than the areas surrounding them. Originally the mapping was undertaken to determine the geology surrounding Bristol, Cadiz, Danby, and Dale Dry Lakes, which are saline producing or potentially saline bearing. Prior to the mapping of this reconnaissance, four holes were drilled in Bristol, Cadiz, and Danby Dry Lakes by the U. S. Geological Survey and their cores logged in detail (Bassett, Kupfer, and Barstow, 1959).

Playa deposits. Thompson (1929, p. 125) divided playas into dry and moist types according to their surface characteristics, which in turn reflect ground water conditions. Dry playas are characterized by hard-packed clay surfaces (Qc) and form where the water table lies far beneath the surface. Moist playas are characterized by

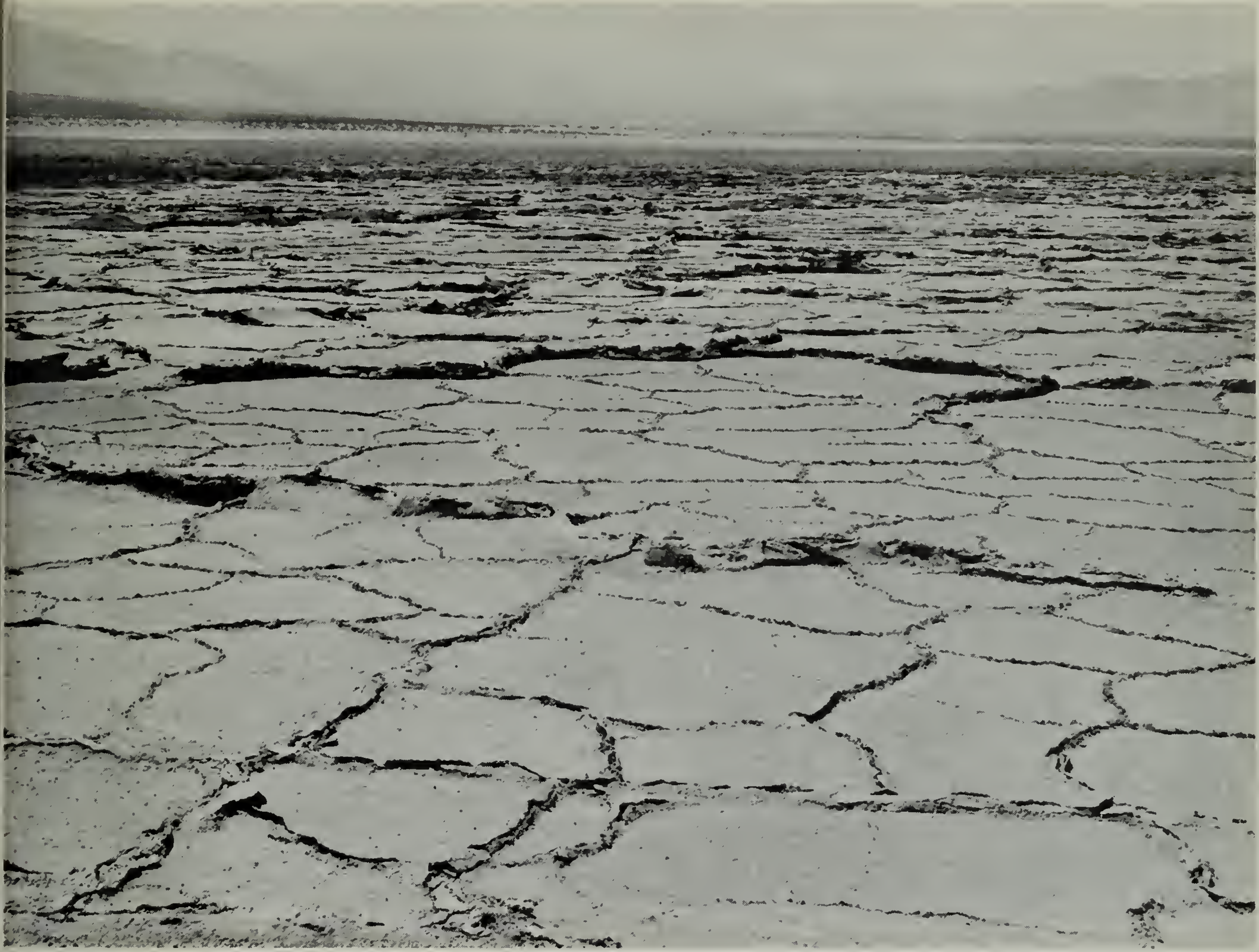


Photo 4. Bristol Dry Lake. *Photo by Mary Hill.*

complex surfaces and form where the water table is at or near the surface. Those parts of a moist playa where the water table is at or above the surface of the playa, are covered with a brine or perennially brine-soaked clay (Qxb). Areas that were once in this condition, but have since had the brine level lowered by evaporation, are now covered by crystalline salts (Qx). In places where the water table is only a few feet below the surface, the water discharges to the surface by capillary action and evaporates, forming a crust of puffy, loosely packed salt mixed with clay or silt (Qxc) known as efflorescent or self-rising ground. Marginal to some of the playas are transitional zones of intermixed alluvial sand and playa clay (Qca).

Along the western edge of Bristol Dry Lake (pl. 1) is an area of gypsum crystals in silt (Qxg) and on Cadiz and Danby Dry Lakes are areas of gypsum-capped pedestals (Qxg). The pedestals are erosional remnants, 4 to 6 feet high on Cadiz Dry Lake and as much as 12 feet high on Danby Dry Lake that are the result of a layer of gypsum crystals that has acted as a protective cap in preventing the looser underlying material from being removed. On Danby Dry Lake the gypsum is 2 feet thick and composed of interlocking gypsum crystals up to 8 inches long.

Durrell (1953b) has described an unusual occurrence of large potato-like concretions of celestite in gypsiferous sandy clay a foot beneath the surface of the playa in the southwestern corner of Bristol Dry Lake. Similar large concretions occur on Cadiz Dry Lake where they are clustered together on the surface of several low pedestals about a foot above the surrounding playa level; the concretions are wind faceted and probably have protected the playa material on which they rest from erosion much as the gypsum layers have protected other pedestals.

The basins of the southeastern Mojave Desert nowhere

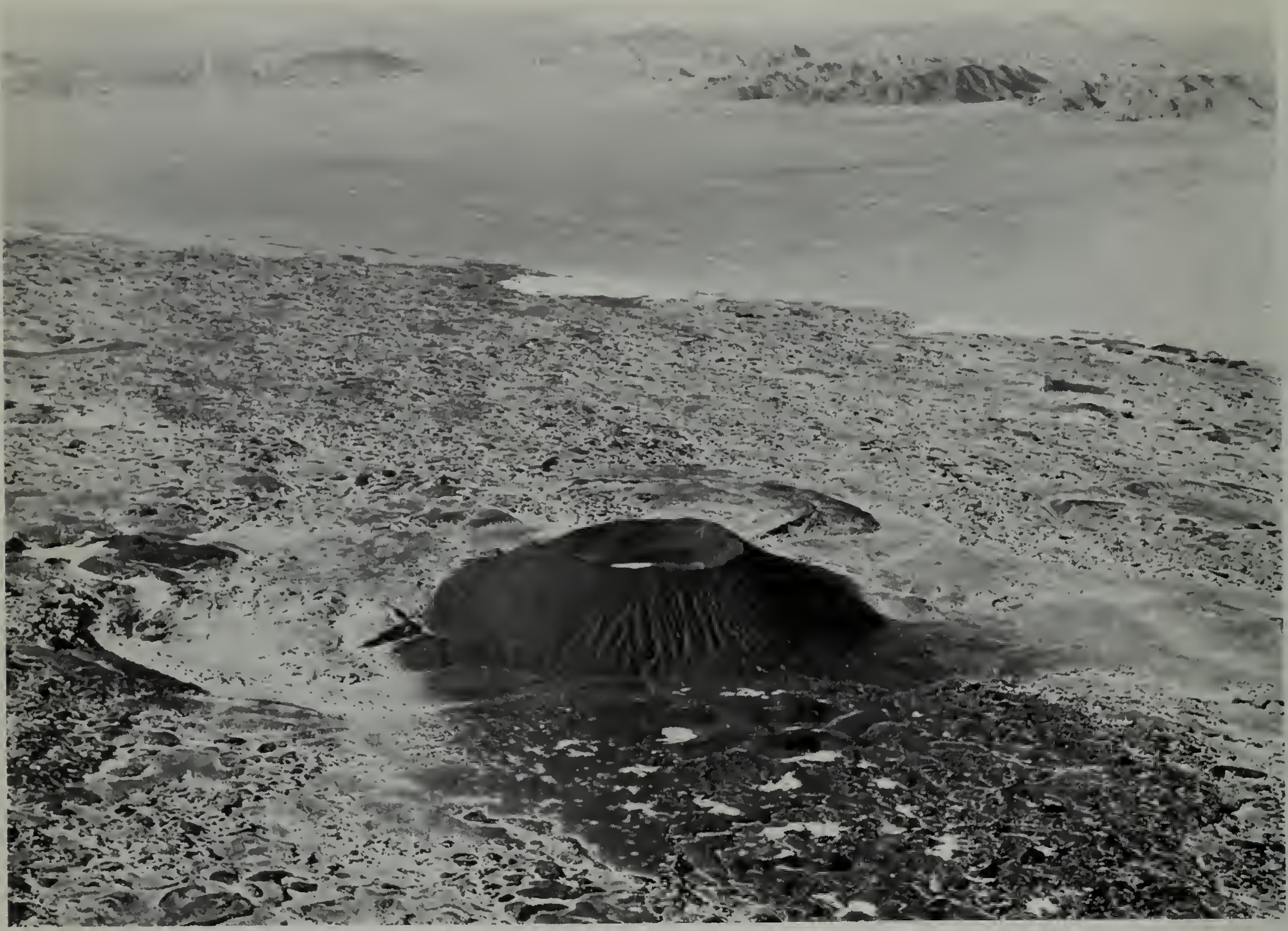


Photo 5. Amboy Crater. View northwest from Bristol Dry Lake toward the Bristol, Old Dad, and Granite Mountains. Route 66 and the Santa Fe Railroad cross the middle ground. *Photo by R. C. Frampton and J. S. Shelton.*

contain ancient shorelines to suggest that their playas resulted from the drying up of Pleistocene lakes. Study of the drill cores taken from Bristol, Cadiz, and Danby Dry Lakes (Bassett, Kupfer, and Barstow, 1959) suggests that the conditions of deposition have been much as they are at present for many millennia. The fact that salt, silt, and clay of the same generally brown color extend all the way from the surface to a depth of 1,000 feet in Bristol Dry Lake, 500 feet in Cadiz Dry Lake, and about 500 feet in Danby Dry Lake, suggests that to these depths at least the sediment was deposited in ephemeral lakes. In Danby Dry Lake at depths greater than 500 feet, however, a set of calcareous silts and laminated green and blue clays, containing fossil barnacles and foraminifera, suggest that these sediments may have been deposited in a permanent and somewhat salty body of water (see Smith, 1960). There is a possibility that the barnacles and foraminifera of typically marine species were deposited in the lower Danby sediments from an arm of the sea, but the details of this hypothesis are too complex and little understood at present to merit discussion here.

Deflation. A question concerning the playa deposits is whether the surface of the playas is currently being aggraded by deposition or degraded by deflation. The evidence for deflation in the southeastern Mojave Desert is probably as clear as anywhere else in the southwestern United States (Blackwelder, 1930). It should be made clear, however, that by deflation the authors refer strictly to lowering by wind transportation of loose material and not to erosion by wind abrasion.

The moist-type playas are covered by an efflorescent crust which, when disturbed, exposes material beneath it that is very loosely packed and hence extremely susceptible to erosion by wind. By contrast, the dry-type playas have a surface that is hard and smooth, offering almost no edges for the wind to catch nor pieces for it to tear loose, except mud cracks and curls.

Specific evidence of deflation on Danby Dry Lake has been discussed by Blackwelder (1931). He interprets the gypsum-capped pedestals near the south-central part of the playa to have formed largely by water erosion, with which the present authors agree; and that this water must have drained into a part of the playa that is lower than the pedestal caps. He believes that this sump was formed by the excavation of part of the playa surface by the action of the wind. Although this seems a perfectly plausible interpretation, it is also possible that either differential compaction, solution and redeposition of the irregularly deposited salt beds, or regional warping could be responsible for the relief of the playa surface, which is now about 15 feet.

On Cadiz Dry Lake, a number of tire tracks made in 1953 have cut ruts 6 inches deep in the dry porous playa crust. Nearby older tire tracks, probably made between 1941 and 1945 during maneuvers for World War II, stand about 3 inches above the surrounding level of the playa crust in the pattern of a raised cameo. This may indicate the removal by deflation of about 9 inches of the less compressed material on either side of the old tire tracks since they were made. Rainfall in the period between 1942 and 1953 was well below normal, probably less than 2 inches per year on the average, and high deflation rates would be expected. However, the relative height of the older tracks might instead be the result of an increased rate of efflorescence in the material that filled the depressed tracks.

Evidence of deflation on Bristol Dry Lake consists of a disparity of about 3 feet between the level of the present playa surface and the base of the Amboy basalt flow that poured out onto the surface of the playa at a time when it must have been higher. The authors believe this lowering of the playa surface was caused by deflation, but some other cause is possible, such as differential compaction of the playa sediments, slight tilting, or erosion toward a lower center.

Quaternary basalt flows and cones (Qb-1 and Qb-2)

The Quaternary basalt flows and cones include those at and surrounding the Amboy and Pisgah Craters (Qb-2) on the floor of the broad valleys, those at Sunshine Peak and Lead Mountain (Qb-2) that have flowed down mountain slopes and are only slightly eroded, and the one at Broadwell Mesa (Qb-1) that is flat lying, moderately eroded, and rests unconformably on tilted gravels (QTg). Some of the basalt flows (QTub) discussed with the undifferentiated Cenozoic rocks may be of Quaternary age, but lack sufficient indications of their youth to warrant including them here.

A very prominent undissected cinder cone, know as the Amboy Crater, is located just southwest of the town of Amboy and southeast of the town of Bagdad (pl. 1). The cone, which is breached on the western side, rises about 200 feet above its associated flows that spread out over an area of nearly 40 square miles. The volcano erupted along the northern border of Bristol Dry Lake and poured lava out onto its surface dividing it into the two present playas, Alkali and Bristol Dry Lakes.

A relatively undissected cinder cone known as Pisgah Crater, just south of U.S. Highway 66 near the Pisgah railroad siding west of Ludlow, rises about 250 feet above basalt flows that extend southward 6 miles to Lavic Dry Lake and northwestward 11 miles. R. D. Allen classified the lava as a microporphyritic microdiabasic olivine-augite basalt with a small amount of magnetite. The cone has been extensively quarried for volcanic cinders.

The flow near Sunshine Peak lies west of Lavic Dry Lake and directly south of the Pisgah Crater (pl. 1). The basalt issued from a cinder cone about 200 feet high perched on the side of a steep slope. Lava poured downward a thousand feet to the edge of Lavic Dry Lake over a very irregular surface including a 200-foot escarpment along a fault that evidently formed just prior to the eruption. The flow is displaced by a Recent fault at its northern end.

A well-preserved cinder cone and an associated flow are located on the south side of Lead Mountain (pl. 1). From a cone 100 feet high, basalt flowed south and east 5 miles down a valley leading toward Bristol Dry Lake Basin. Because this lava flow has been dissected to a slightly greater degree than the three flows described above, it is believed to be somewhat older. One mile north of the main flow and at the base of Lead Mountain are two outcrops of basalt about 3,000 feet long. These were not visited, but their topographic position 200 feet above the main flow suggests that they may be erosional remnants of a still older flow; they are designated as undifferentiated basalt (QTub) on the map.

A dissected basalt flow caps Broadwell Mesa in the northwestern Bristol Mountains. The basalt is about 2 to 6 feet thick and flowed out over a relatively flat surface of erosion near the crest of the range. The west edge of the present remnant of the original flow is about 300 feet higher than the east end and the source of the flow was probably still higher and to the west. This flow lies with slight unconformity on tilted gravels (QTg) but is in distinct angular unconformity on the gravels and pyroclastic rocks (QTvg) and the volcanic rocks (QTv) of the sequence at Broadwell Mesa. It is distinctly younger than the older Cenozoic basalt (QTvb) at Broadwell Mesa and is untilted, yet its cinder cone and a portion of the flow have been removed by erosion, suggesting an age intermediate between the older Cenozoic rocks and the very

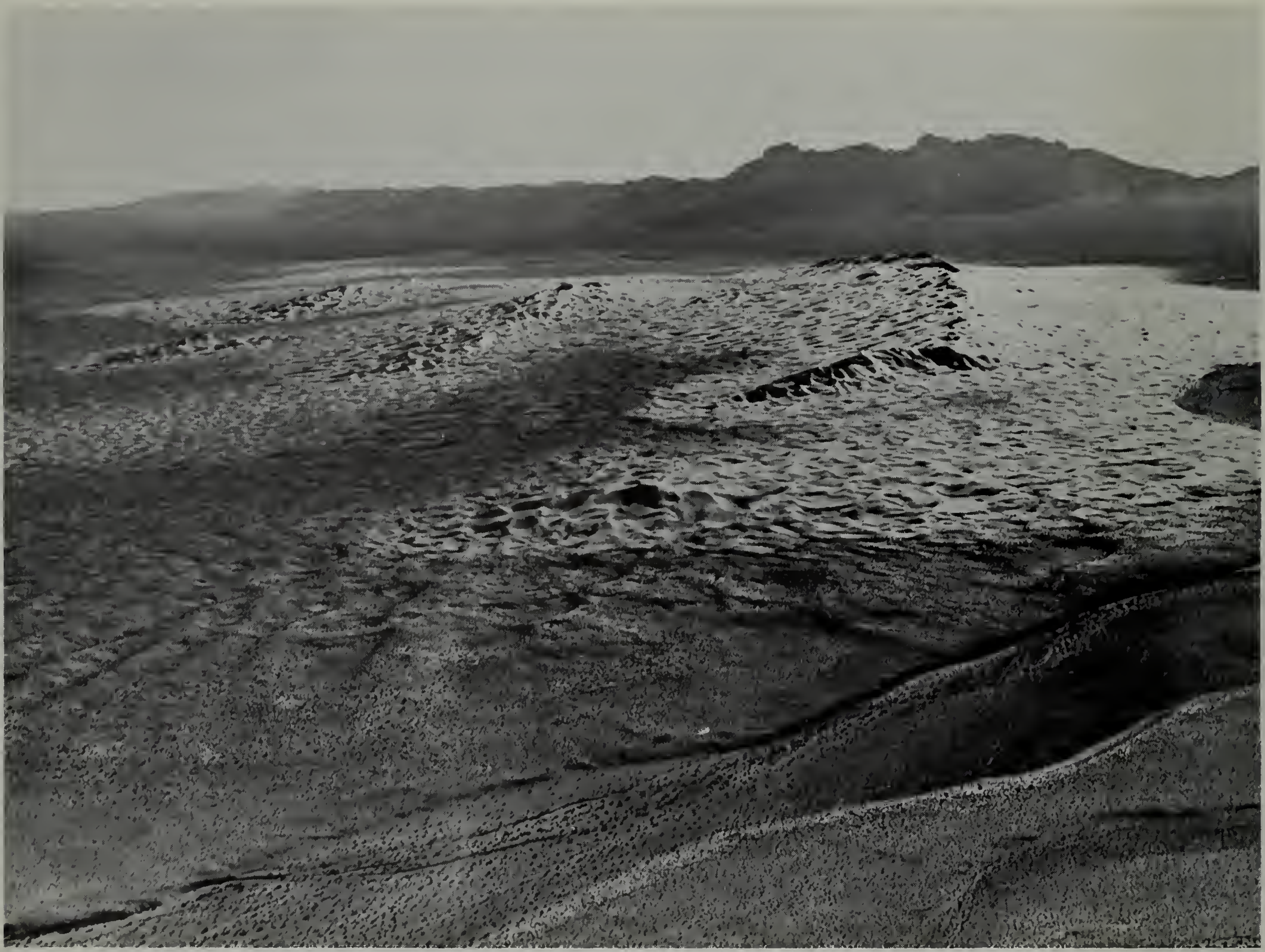


Photo 6. The Kelso Dunes. *Photo by R. C. Frompton and J. S. Shelton.*

young Quaternary basalt flows (Qb-2). Unlike the younger basalts, its olivine phenocrysts are partly altered to iddingsite, but the alteration is not as pronounced as in the older basalts. A thin section of this rock was examined by R. D. Allen who described the basalt as a microporphyritic microdiabasic basalt composed of olivine (partly altered to iddingsite), augite and labradorite with a small amount of magnetite.

Modern alluvium (Qa)

Modern alluvium consists of fan gravels, stream gravels, and other alluvium being deposited by the present drainage system. The fan gravel ranges in size from boulders several feet in diameter that typically occur near the base of the mountains to coarse sand at the margins of the playas.

Some idea of the thickness of the alluvial fill in the basins can be obtained from drill holes; these thicknesses, however, necessarily include material equivalent in age to the older alluvial deposits (Qoa) that can be distinguished only physiographically at the surface. Thompson (1929, p. 696) described a well near Bagdad that struck "granite" at 805 feet below the surface and another at Amboy that struck bedrock at 1,500 feet. He questioned the latter depth as it was below sea level, but it is in agreement with the recent deep holes on Bristol Dry Lake (Bassett, Kupfer, and Barstow, 1959) which penetrated to 400 feet below sea level without reaching the bottom of playa deposits. Alluvial deposits in small basins may be expected to have a thickness of several hundred feet, and in the larger basins may be expected to exceed 1,000 feet.

Wind-blown sand deposits (Qs and Qsd)

The prevailing winds of the Mojave Desert are from the west. Much of the wind-blown sand picked up in the wide expanses of flat country in the western Mojave

Desert is carried into this southeastern region and deposited as sheets (Qs) and dunes (Qsd). Dunes generally form against obstructing hills or ridges in the southeastern corners and along the eastern edges of open basins and troughs. Each winter and spring strong winds carry great clouds of sand and finer-grained materials down the Bristol-Cadiz-Danby trough forming large areas of dunes east of Cadiz Dry Lake that practically bury the low Kilbeck Hills (pl. 1). The area around Dale Dry Lake is covered by thick deposits of dune sand; and the western slope of the Cady Mountains is virtually buried beneath sand that has blown across the open valley that lies to the west.

The most spectacular dunes are the Kelso dunes in the northeastern corner of the area, north of the northern Granite Mountains, and near the station of Kelso on the Union Pacific Railroad (pl. 1). The highest dune in this group rises over 700 feet above the alluvial slope on which it formed, and is one of the highest sand dunes in the United States.

Rounded mounds of windblown sand topped by brush, some of which are 12 feet high, occur on the playas, particularly on Cadiz Dry Lake. These mounds are constructional features formed by an accumulation of drifting sand around the base of plants that originally grew at playa level. As the sand accumulated, the brush grew higher. The present tops of the plants are connected to the roots in the moist playa mud by long stems that hold the sand mounds in place.

All the windblown sand is of Recent age and rests on alluvial fans graded to present basin floors.

UNDIFFERENTIATED CENOZOIC ROCKS

The undifferentiated Cenozoic rocks have been divided into undifferentiated basalts (QTub) for basalt flows that could not be assigned to a particular rock sequence, and undifferentiated volcanic rocks (QTuv) for all other Cenozoic deposits, most of which are volcanic, that could not be correlated with known sequences.

Undifferentiated basalt (QTub)

Basalts are difficult to correlate in the Mojave Desert region. They appear to have no consistent differences in physical properties that can be reliably used to correlate scattered exposures or that can be related to geologic age. There is good evidence for at least five different periods of basalt extrusion during the Cenozoic history of this region, and it is likely that twice that many would be a conservative guess. This has necessitated mapping outcrops of basalt that are isolated from the main rock sequences as undifferentiated (QTub).

The undifferentiated basalt flows along the western edge of the northern Bullion Mountains, near the Bullion fault zone, all appear to be of approximately the same age. After deposition of the pyroclastic rocks and basalt (Tp) and the overlying andesite (Ta), there appears to have been an uplift of the mountain range along the Bullion fault zone. Later erosion destroyed the fault scarp and formed a pediment. Basalt then issued from vents along the Bullion fault zone and parallel breaks within the Bullion Mountains, and flowed down the slope of the pediment. The basalt was later offset by further movement along the Bullion fault zone and in part buried by gravel deposits that have since been tilted (QTg). These basalt outcrops in all probability were never continuous, but instead represent isolated vents and local flows, as do the known Quaternary basalt flows (Qb-1 and Qb-2). Because it is difficult in some instances to distinguish the basalt of the pyroclastic rocks and basalt unit (Tp) from the later basalt (QTub) that lies on it unconformably, it is possible that some of the undifferentiated basalt in the northern Bullion Mountains actually belongs to the earlier unit.

Gardner (1940, p. 284) assigns basalt of comparable age just west of the northern Bullion Mountains to a formation called "Black Mountain Basalt", presumably intending correlation with the basalt of Black Mountain some 100 miles to the northwest. These basalts may well be of about the same age, but the present writers believe such long-range lithologic correlation, especially of basalts, is unjustified.

At the northern end of the Bullion Mountains, in the hills just south of Ludlow (pl. 1), the erosion that took place between the deposition of the andesites (Ta) and the undifferentiated basalt (QTub) was less extensive—the basalt appears to rest conformably on the andesite in individual outcrops, but in broader aspect an unconformity is evident.

West and northwest of Bagdad (pl. 1) are a number of basalt cinder hills that may well be of Pleistocene age but are distinctly older than the Quaternary basalt flows in the valleys (Qb-2). One such hill, a few yards south of U. S. Highway 66, retains the form of a cinder cone breached at the northeast side. The hill rises 160 feet above an alluvial fan, which has buried any associated flows. North of the highway, another poorly formed cinder cone about 500 feet high has been quarried commercially for volcanic cinders.

Undifferentiated volcanic rocks (QTuv)

Two different categories of rock are included in this unit. One category includes rocks known to be of Cenozoic age, but not well enough known to be correlated with other rock units in the map area. The other category includes rocks of known lithology and correlation, but of such intricate outcrop pattern that the details cannot be differentiated at the scale of the reconnaissance map (pl. 1).

In the northern Bullion Mountains, rocks of this unit consist of pyroclastic rocks and basalt (Tp), andesite (Ta), and intrusive quartz latite porphyry (Tql). They are labeled as undifferentiated volcanic rock (QTuv) with the symbols for the components of the mixture given in parentheses. Actually all of the undifferentiated volcanic rocks of the northern Bullion Mountains are probably correlative with one or more of the established rock units.

In the Cady Mountains the undifferentiated volcanic rocks in the eastern part of the range are predominantly fine-grained pyroclastic rocks that may be equivalent to the Miocene sedimentary rocks (Tms) of the northern Cady Mountains. They are overlain by coarser agglomerate and flow breccia that may be equivalent to the volcanic conglomerate and breccia facies (Tmv). On the western slope of the central granitic mass is a wide variety of volcanic rocks whose sequence was not deciphered. Andesitic cinder breccias, basaltic and andesitic lavas, vitrophyric rocks, and many other rock types lie beneath a dissected pediment. At the north edge of this, and adjacent to the Cady fault zone, are bright-green, fine-grained pyroclastic rocks. In the southwestern spur of the Cady Mountains the undifferentiated volcanic rocks are predominantly andesitic and latitic flow breccias overlain in angular unconformity by a volcanic conglomerate and gray vitrophyre that are in turn overlain by undifferentiated basalt (QTub). All of these may be correlative with the Miocene rocks of the northern Cady Mountains, but lie on the opposite side of a large fault and are not well enough known to be treated as equivalent.

The undifferentiated volcanic rocks of the central and southern Bristol Mountains are probably equivalent to the lower part of the sequence at Broadwell Mesa (QTv), but are not so indicated because the areas either were never visited or were visited too briefly to confirm this correlation. Many of these rocks are coarse cinder breccia, probably andesitic, and very coarse agglomerate which is light colored and probably latitic or dacitic.

In the Old Dad Mountains, the lava flow remnants (QTuv) that cap the tuff and breccia (QTt) are nearly flat lying and probably of more than one rock type. In part they are known to be basalt, both scoriaceous and massive, but several specimens collected at the base of the lava-capped hills proved to be rhyolite and one specimen near the north end of the range was andesite. An ancient high surface, perhaps in part erosional and in part the flat tops of lava flows, exists across all of these lava-capped hills. It may represent a pediment and have a gravel veneer on it, which may account for the diversity of rock types found at the base of the hills.

STRUCTURAL GEOLOGY

Cenozoic tectonic activity in the southeastern Mojave Desert is manifested chiefly by faulting and tilting; folding is minor and generally related locally to the faulting. Most of the faults have generally straight traces and are presumably high-angle faults. Northwest-trending faults predominate, creating the linearity of the mountain ranges. The only other major fault trend within the region is eastward, exhibited by three fault zones in the western part of the area. Two very minor thrust faults were observed.

Pre-Cretaceous structural features of the region were obliterated by the late Mesozoic igneous intrusions and by the extensive early Cenozoic erosion and later Cenozoic faulting and tilting.

FAULTS

Most of the faults were discerned from air photographs, and the type and magnitude of their displacements could not be determined with certainty. On some there is evidence of vertical displacement, as much as several thousand feet. On some of these and on others there is evidence suggestive of lateral displacement. Such evidence consists of the angles between the faults and the axes of folds adjacent to them, and the presence of high blocks alternating on opposite sides of a fault. This evidence leads to the very tentative generalization that in most instances the dominant movement is right lateral on the northwest-trending faults and left lateral on the east-trending faults. In the area west of this reconnaissance there is evidence suggestive of displacement on the order of several miles laterally on several northwest-trending faults.

The time of the earliest movement on the major faults is not known, but displacements had developed shortly after deposition of the andesite of the northern Bullion Mountains (Ta) and the Miocene rocks of the northern Cady Mountains (Tms, Tmb, Tmv, Tmf). In the area as a whole displacements on the faults appear to have occurred intermittently to Recent time, and several earthquakes have occurred in the area within the last few decades.

Northwest-trending faults

Mesquite Dry Lake fault

The Mesquite Dry Lake fault, apparently a single break 16 miles long, extends N. 30° W. from Twentynine Palms to Gypsum Ridge. It is sharply delineated on air photographs by the growth of bushes on the southwest side and the absence of vegetation on the northeast side, which indicates its action as a barrier to eastward moving ground water. The principal displacement is probably strike slip and the sense is probably right lateral based on the west-northwest direction of fold axes in Gypsum Ridge, adjacent to the zone and on the conclusions reached by T. H. McCulloh * and T. W. Dibblee, Jr., (oral communications, 1957) from studies farther north on this same fault zone. Movement on the fault is responsible for the local folding in the small hills a few miles east of Twentynine Palms, but along most of its course the fault exhibits no surface relief, lending support to the suggested strike-slip displacement. The magnitude of displacement is not known. The fault is apparently terminated southward by the east-trending Pinto fault zone, but the junction is not exposed.

Bullion fault

The Bullion fault forms the southwestern border of the northern Bullion Mountains; parallel faults along the same trend cut through Valley Mountain northeast of Twentynine Palms and extend into the Pinto Mountains southwest of Dale Dry Lake (pl. 1). These form a zone that is practically a single line striking N. 40° W. In detail the fault is composed of many shorter discontinuous overlapping breaks, ranging from 100 feet to a mile in length. At the scale of the geologic map (pl. 1) these short faults are shown as a single break. The presence of high blocks alternating on opposite sides of the fault suggests lateral displacement.

The strip between the Bullion and Mesquite Dry Lake fault zones forms a narrow graben about 30 miles long, in which were deposited Pleistocene(?) sediments (QTs) that have been deformed into the anticlines, synclines, and domes of the Gypsum Ridge Hills by movement along the bordering faults. The axes of these folds trend west-northwest, suggesting that displacements along the fault zones were right lateral.

Extensive movement on the Bullion fault has occurred subsequent to the deposition of the andesite of the northern Bullion Mountains (Ta). The fault zone probably acted as a conduit for the undifferentiated basalt (QTub), as indicated by the three small basalt hills that lie astride the fault adjacent to the northern Bullion Mountains, and movement along the fault probably continued after eruption, as shown by slight offsets of this basalt. There does not appear to have been any displacement in Recent time; no offset drainage channels or broken alluvial fans were observed.

Death Valley fault zone problem

Some speculation has centered about the southern extension of the Death Valley fault zone, which has been traced into Soda Lake (Grose, 1959) but not south of it. A hypothetical fault is shown by Hewett (1955) passing between the Old Dad and Granite Mountains and extending along the southwest side of the Marble Mountains just east of the present reconnaissance. A search in the field and on air photographs for this fault in the valley between the Old Dad and Granite Mountains failed to reveal any positive evidence to support it.

The mountain ranges to the east of this hypothetical line trend north and even northeast, whereas the ranges to the west have the northwest trend that dominates the southern Mojave Desert. This hints that a deep-seated structural shear may lie along this line and may represent a southward continuation of the Death Valley fault zone.

A fault that strikes about N. 20° W. bisects the hills of basement rock that lie northeast of the Bristol Mountains (pl. 1). Though its strike does not conform to the general trend of the Death Valley fault zone, it might represent a southern continuation of that zone inasmuch as it lies approximately along the extension of the fault from the Soda Mountains. There is no evidence of its extension to the southeast.

Other northwest-trending faults

A sharply delineated fault cuts through the basalt flows near Sunshine Peak and Pisgah Crater at the western edge of the map (pl.1). Displacement along this fault may have been genetically related to the eruptions, inasmuch as basalt from the crater near Sunshine Peak cascaded down the east-facing escarpment of the fault, yet is offset by the same fault just a short way north. Likewise, the flow from Pisgah Crater was guided between hills of gravel uplifted by the fault, yet was, itself, cut by later movement on the same fault in which the west side was dropped about 6 feet as can be seen where it crosses U. S. Highway 66.

A fault on the western side of the Sheep Hole Mountains (pl. 1) forms a steep wall with over 2,000 feet of relief, sharply separating the dissected older alluvium from the pre-Cenozoic rocks of the mountains. A northward extension of this fault zone has created the narrow fault valley in which lie the Cleghorn playas. An earthquake with magnitude greater than 5.5 is shown by Richter and Gutenberg (1954) to have had its epicenter just north of the Cleghorn playas, probably on this fault zone.

The fault zone that passes through the hills just south of the town of Ludlow, and extends northwest into the southeastern Cady Mountains and southeast to Lead Mountain (pl. 1), strikes N. 40° W. and is nearly 40 miles long. The several northwest-trending faults of this zone in the southeastern Cady Mountains were mapped by Durrell (1953a, p. 39) who states: "most of the faults of this system are reverse faults that dip toward the southwest * * *" This observation was not checked in the present reconnaissance. The epicenter of an earthquake of magnitude 5¾ that occurred on July 18, 1946 is indicated as being along this fault zone northwest of Lead Mountain and about 10 miles southwest of Bagdad; another one of less magnitude is shown about a mile farther north, probably also related to this fault zone (Richter and Gutenberg, 1954, p. 21).

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* McCulloh, T. H., 1952, Geology of the southern half of the Lane Mountain quadrangle, California: California Univ. (Los Angeles), Ph.D. thesis.

Many of the northwest-trending mountain ranges probably are bordered by faults of large displacement, any trace of which has been buried beneath the alluvium derived from erosion of the uplifted mountains. Such hypothetical faults are not shown on the map. Probably many faults that are exposed were overlooked in so rapid a reconnaissance.

East-trending faults

Pinto Mountain fault zone

The Pinto Mountain fault zone is the longest and physiographically most prominent of the east-trending fault zones in the southern Mojave Desert. It extends from the San Andreas fault near San Gorgonio Peak, eastward along the north side of the Little San Bernardino and Pinto Mountains (Allen, 1957), to the southwest corner of this reconnaissance (pl. 1). The springs that support the palm grove, for which the town of Twentynine Palms was named, issue from this fault where it passes just south of the town. East of Twentynine Palms it is intersected by the Mesquite Dry Lake fault with a complex fault pattern resulting. Several short breaks striking east-southeast from this fault junction appear to indicate a breaking up of the Pinto Mountain fault zone. The persistent east-striking alinement of the north front of the Pinto Mountains strongly suggests that in the past some east-trending fault probably extended from Twentynine Palms to the Sheep Hole Mountains. The trace of such a fault is not exposed.

The western part of this fault zone has been studied in detail by Allen (1957, p. 342) who says of it: "Nowhere is the attitude of the fault plane discernible, although the relatively straight course of its trace across rugged topography suggests a steep dip." He adds further: "There is no direct evidence for lateral displacement along the fault, but this type of movement is made plausible by evidence of varying vertical component of movement, and by the exceptionally uniform trend of the fault trace." His observation that this zone marks the southward termination of the northwest-trending faults of the Mojave Desert appears applicable only to those west of the Mesquite Dry Lake fault. This northwest-trending fault appears to have disrupted or perhaps offset the Pinto Mountain fault zone, and about 10 miles east of the junction the southernmost trace of the Bullion fault zone appears to have completed the disruption. Still farther east, probable northwest-trending faults extend without interruption along the front of the Calumet and Coxcomb Mountains.

In the vicinity of Twentynine Palms a number of arches and buckles in the gravel deposits and several smaller faults right at the junction between the Pinto Mountain and Mesquite Dry Lake fault zones, suggest that a detailed study there might yield information on the time relationships of the two major fault trends.

Cady fault zone

The Cady fault zone, which was first shown by Hewett (1954, pl. 1), but first named in the present paper, strikes due east through the center of the Cady Mountains (pl. 1), separating relatively high mountains to the south from an enclosed alluvial valley to the north. No conclusive indication of type or direction of movement was observed, but with the south side up throughout its length and with the fault's abrupt termination eastward, it appears to be of vertical displacement. In the few places where breaks were visible, the fault dips steeply north, indicating that it would be normal.

On the south side of the zone, a number of northeast-striking fractures and two relatively strong northeast-trending faults appear to be related to the displacement of the Cady fault. This northeasterly fault trend occurs only rarely in the region.

Manix fault zone

The Manix fault zone (pl. 1) is a major active fault in the east-central Mojave Desert. It is well exposed in the canyon of the Mojave River south of Field, also along the north edge of the Cady Mountains, through Afton Canyon, and in a possible continuation of the same zone in the Mesquite Hills south of Crucero.

The fault zone strikes slightly north of east. In places it is several thousand feet wide and made up of many anastomosing breaks. It separates thick gravel deposits (QTg) on the north from brecciated slivers of Tertiary volcanic rocks (Tmf) on the south. In Afton Canyon a zone of intensely fractured, sheared, and altered rock over 1,000 feet wide separates thick Tertiary sedimentary rocks (Tms) on the south side of the canyon from basement granitic and metamorphic rocks on the north side. At the east end of Afton Canyon the fault zone appears to break up into divergent traces, most of which are lost under the alluvium near Crucero basin, but the southern branches of which appear to continue along the south border of that basin and into the Mesquite Hills.

Displacement on the zone may have begun as early as late Tertiary time but definitely has continued intermittently throughout the Quaternary. The most recent earthquake of the region was the result of movement on this fault, just southeast of Manix, in 1947 (Buwalda and Richter, 1948). It had an instrumental magnitude of 6.4 on the Richter scale. This earthquake was discussed by Richter and Gutenberg (1954, p. 19) who state:

> "April 10, 1947. Southeast of Manix, Mojave Desert; left-hand strike slip movement of only a few inches along the line of the Manix fault; instrumental locations of epicenters of aftershocks aligned nearly at right angles to this fault, suggesting that the observed displacement is a secondary result of a larger displacement on a fault with different strike in the basement rocks."

The Manix fault zone formed the northern limit of this reconnaissance and was not studied in sufficient detail to arrive at definite conclusions regarding the type and magnitude of displacement. However, the braided or anastomosing tendency of the fault trace and the presence of high blocks on both sides of the fault suggest strike-slip displacement, and the direction of the fold axes in the Miocene rocks adjacent to the fault zone suggest that the displacement is left lateral.

Small thrust faults

In view of the many thrust faults reported just north and northeast of the area of this reconnaissance, namely at Bitter Spring 12 miles north of Afton Canyon (Hewett, 1954, p. 17) and in the Ivanpah quadrangle (Hewett, 1956, p. 275), it is significant that no convincing evidence of large thrust faults and very little evidence of minor thrusts was found within the area of this reconnaissance.

A thrust fault that is probably minor coincides in part with an unconformity, and is exposed in the north face of Pacific Mesa in the northern Bullion Mountains at the base of the sequence of sediments and tuffs (QTps) (pl. 1). This thrust cuts transversely across the tilted underlying sequence of gravels and volcanic rocks (Tpg) truncating several units of the sequence. Well-developed grooves on a slickensided surface strike N. 75° W. and dip 20° S.; but the thrust plane itself is generally horizontal with undulations.

A well-exposed but very small thrust fault was observed at the northeast corner of the valley just north of the Cady fault in the central Cady Mountains (pl. 1), where tilted and lithified brown granitic gravels (QTg) are thrust over flat-lying, white granitic and volcanic gravels that are interpreted to be younger (Qoa). The thrust surface strikes N. 65° E. and dips 13° NW., and striae on the surface trend north.

The surface traces of these two small thrusts are too limited in extent to be shown on the geologic map (pl. 1).

FOLDS

Folds in the southeastern Mojave Desert are minor structural features, present only at a few places and usually related to nearby or adjacent faults. Inasmuch as very few attitudes were measured during this reconnaissance, many small folds probably have been overlooked.

Tertiary sedimentary rocks in the south wall of Afton Canyon are folded into northwest-trending anticlines and synclines, some nearly isoclinal. Presumably these are a result of the forces that caused lateral displacement along the Manix fault zone.

In the southeastern Cady Mountains, a southeast-plunging anticline has probably resulted from the forces that created the Ludlow fault zone, which dies out in this area. The form of the anticline is modified by a northwest-trending fault approximately along the axial plane. Further folding in the southeastern Cady Mountains is discussed by Durrell (1953a, p. 39) who says: "The Tertiary rocks of the area have been folded twice and perhaps three times." This he apparently bases on unconformities between stratigraphic units, but such repeated folding is not known elsewhere in the southeastern Mojave Desert; perhaps some of the folding to which he refers is actually block tilting due to fault displacement.

Several anticlines and synclines and also a well-developed dome form Gypsum Ridge that lies in the valley just southwest of the front of the Bullion Mountains. The hills are bordered on the west by branches of the Mesquite Dry Lake fault zone and on the east by the Bullion fault zone. The axes of the folds strike consistently northwest at an angle more westerly than the faults.

The half-dome fold of the small hill just east of Twentynine Palms, as well as other less well-formed folds in the gravels within and north of the town, are interpreted as pressure ridges resulting from the forces acting on both the Mesquite Dry Lake fault and the Pinto Mountain fault zone.

Finally, the tilted section of gravels and volcanic rocks (Tpg), on which the sedimentary rocks and tuffs (QTps) and the rhyolite tuffs (QTpr) of Pacific Mesa rest in angular unconformity, is folded at the base and top. The basal gravels are believed to go over the crest of an anticline at the west end of the section, and the topmost units are believed to form a very shallow syncline at the east end.

BRISTOL-CADIZ DANBY TROUGH

The three principal playas of the area, Bristol, Cadiz, and Danby Dry Lakes, lie in a large trough that passes through the center of the southeast Mojave Desert, transverse to the dominant structural trend of the region. It has been suggested by Blackwelder (1933, p. 471), Hubbs and Miller (1948, p. 84), and Hewett (1955, p. 377) that an integrated drainage system once connected the western Mojave Desert or Death Valley with the Colorado River by way of the Bristol-Cadiz-Danby trough. The principal reasons for this hypothesis have been (1) the need to explain the occurrence of so large a trough whose axis is transverse to the trend of the individual mountain ranges, (2) the need for a waterway connection between the Mojave River and the Colorado River in order to account for the presence of certain species of fish in the Mojave River and Death Valley (Hubbs and Miller, 1948), and (3) the need to remove large quantities of material from the Mojave Desert in late Pliocene and early Pleistocene time (Hewett, 1955).

The continuation of playa sediments several hundred feet below sea level in Bristol and Danby Dry Lakes, and probably also in Cadiz Dry Lake indicates that this trough was at least partly of structural origin. Further, some means other than a direct water connection possibly could account for the distribution of the now isolated fish. But it is indeed difficult to account for the removal of the large amount of rock debris from the Mojave Desert, even from just the southeastern part, without postulating some integrated drainage leading outside of the desert area and to the sea. The suggestion that this trough is partly the result of structural downwarping does not preclude the possibility that it might also have sustained an integrated drainage system.

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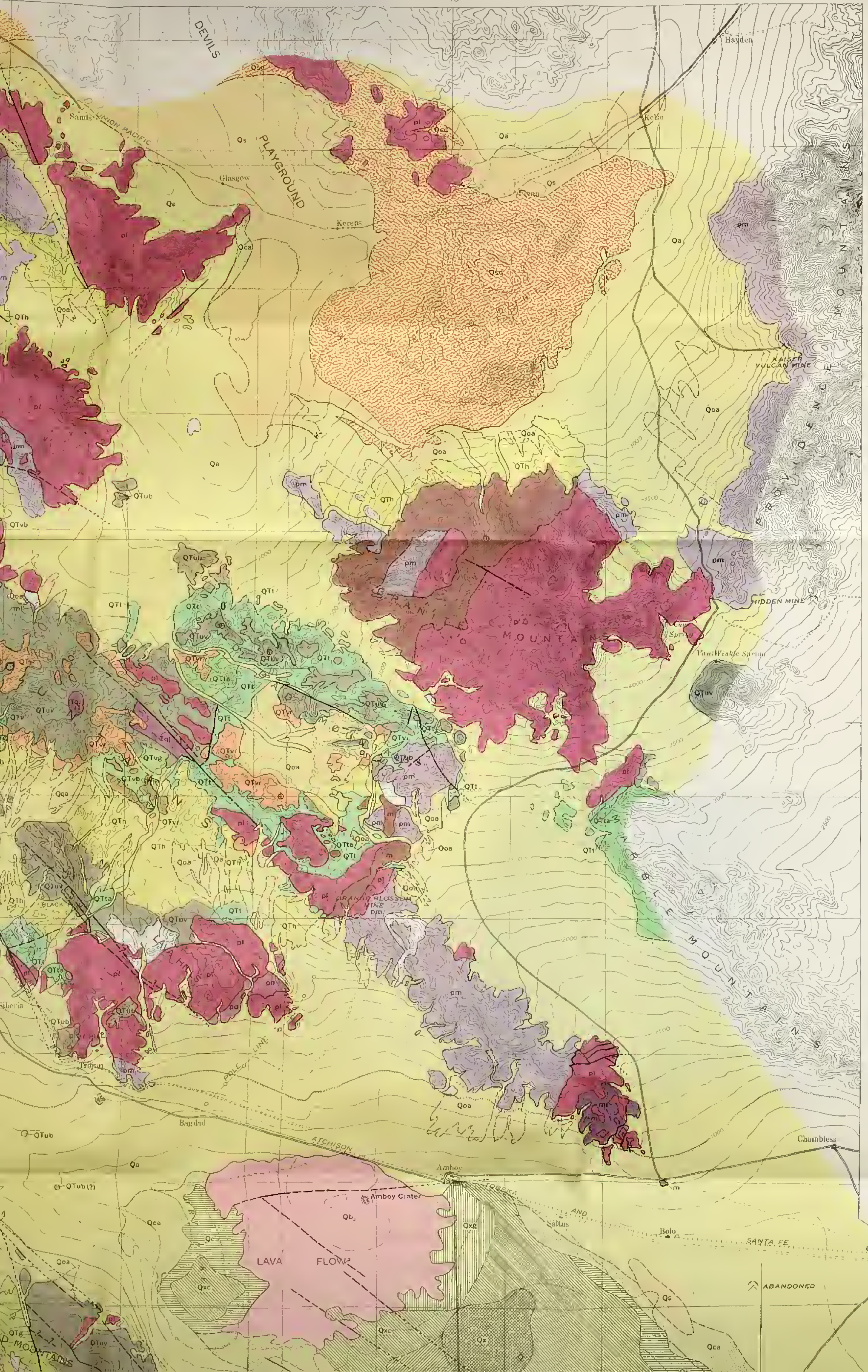
UNITED STATES GEOLOGICAL SURVEY

STATE OF CALIFORNIA THE RESOURCES AGENCY DEPARTMENT OF CONSERVATION DIVISION OF MINES AND GEOLOGY



EXPLANATION

Qs | Qsd

Wind-blown sand

Qs, *in sheets*
Qsd, *in dunes*

Qa

Alluvium

Valley fill, alluvial fan deposits, stream gravels, talus, and other modern deposits.

Qca | Qc | Qxc | Qx | Qxb | Qxg

Playa deposits

Qca, *mixed playa clay and alluvium*
Qc, *hard-packed clay*
Qxc, *mixed salt and clay or silt; efflorescent ground*
Qx, *salt crystal body at or near surface*
Qxb, *mud, salt, and brine in perennially wet sink areas*
Qxg, *gypsum-capped pedestals on Cadiz and Danby Dry Lakes, mixed gypsum and silt on Bristol Dry Lake*

Qb2

Quaternary basalt flows and cones

Undissected cinder cones and associated flows; some rest on playa surfaces

Qoa

Older alluvium

Dissected alluvium related to present drainage pattern; usually dark with desert varnish

Qb1

Basalt

Flat-lying, dissected flow of Broadwell Mesa

QTh

High gravels

Flat-lying, dissected gravels topographically high and unrelated to present drainage

QTg

Tilted gravels

Tilted, dissected, and moderately consolidated gravels

QTs | QTb

Pleistocene(?) sediment and basalt

QTs, *granitic gravel, sandstone, and clay near Twentynine Palms; very coarse boulder gravel and clay in Pinto Basin*
QTb, *tilted basalt interbedded with sediments of Pinto Basin*

QUATERNARY

ANGULAR UNCONFORMITY

Rock units applicable only within each geographic column and no time correlation between columns is implied

QTuv

Undifferentiated volcanic rocks

Undifferentiated rocks of Cenozoic age, mainly volcanic; in northern Bullion Mountains volcanic rocks of known lithology and correlation, but too complex to separate on the map. Symbols in parentheses on map indicate rocks included in unit

QTub

Undifferentiated basalt

Basalt flows of several ages, uncorrelated with basalts in other rock sequences

NORTHERN BULLION MOUNTAINS

QTpr

Rhyolite tuff

Phenocrysts of opalescent blue sanidine, albite, and biotite; exposed on Pacific Mesa

PROBABLE ANGULAR UNCONFORMITY

QTps

Sedimentary rocks and tuffs

Basal conglomerate, fluvial and lacustrine tuffaceous sediments, and pumice tuff; exposed at Pacific Mesa

ANGULAR UNCONFORMITY, FAULTED

Tpg

Gravels and volcanic rocks

Gravels, andesitic basalt, tuffaceous sandstone, shale, dacitic pebble tuff, and talus or landslide breccia; exposed near Pacific Mesa

PROBABLE UNCONFORMITY

Tql

Quartz latite porphyry intrusive

Ta

Andesite

Massive andesite flows with minor interbedded pyroclastic material

LOCAL DISCONFORMITY

Tp

Pyroclastic rocks and basalt

Intermediate and mafic pyroclastic rocks with interbedded basalt flows

SOUTHEASTERN CADY MOUNTAINS

Tl

Lacustrine sedimentary rocks

Clay, tuff, and limestone containing celestite and jasper beds; grades into gravels

Tr

Welded rhyolite tuff

Quartz and iridescent sanidine phenocrysts

UNCONFORMITY

NORTHERN CADY MOUNTAINS

Tms | Tmb | Tmv | Tmf

Miocene volcanic and sedimentary rocks

Tms, *sedimentary rocks: Fossiliferous tuffaceous sandstone, gravels, and interbedded pumiceous pyroclastic beds with rhyolite flows or sills*
Tmb, *basalt: Flow interbedded with sediments*
Tmv, *volcanic conglomerate and breccia: Very coarse boulder conglomerates, agglomerates, and breccias of latitic to andesitic composition*
Tmf, *flows: Thick mafic and intermediate lava flows*

BRISTOL AND OLD DAD MOUNTAINS

QTvr

Rhyolite flows and tuffs

Dense, gray, banded rhyolite flows; lavender tuffs with phenocrysts of opalescent blue sanidine and biotite; perlite and pumice

QTvg | QTvb | QTv | QTt | QTta

Volcanic and clastic complex

QTvg, *gravels and pyroclastic rocks: Granitic gravels, tuffaceous sandstone, and tuff*
QTvb, *Basalt flows: Altered basalt interbedded with gravels and pyroclastic rocks*
QTv, *volcanics: Andesitic agglomerates, breccias, and tuffs; volcanic conglomerates; interbedded andesite and basaltic andesite flows*
QTt, *tuffs and breccias: Lapilli tuff, breccia, agglomerate, tuffaceous sandstone, and volcanic conglomerates*
QTta, *andesitic breccias and flows. Andesitic cinder breccias and agglomerates, andesite and basaltic andesite flows*

Tql

Quartz latite porphyry, intrusive

TERTIARY OR QUATERNARY

TERTIARY

MAJOR REGIONAL UNCONFORMITY

m | mf | mg | ml | mv

Metamorphic rocks

m, *undifferentiated metamorphic rocks*
mf, *foliated metamorphic rocks*
mg, *gneissic rocks*
ml, *crystalline limestones*
mv, *metavolcanic rocks*

pm

Undifferentiated plutonic and metamorphic rocks

pl | pd

Plutonic rocks

pl, *light-colored, quartzose rocks, mostly quartz monzonite and granodiorite*
pd, *dark-colored rocks, mostly hornblende diorite*

PRE-TERTIARY

☐

Rocks of unknown age and lithology in areas not visited

Contact, showing direction of dip

Dashed where approximately located or gradational

Fault, showing direction of dip

Dashed where approximately located, dotted where concealed, queried where questionable

Anticline

Showing trace of axial plane and direction of plunge of axis. Dashed where approximately located

Syncline

Showing trace of axial plane and direction of plunge of axis. Dashed where approximately located

Strike and dip of beds

Approximate strike and dip of beds

f, flat; m, moderate; s, steep

⊕

Horizontal beds

Strike and dip of foliation in crystalline rocks

Approximate strike and dip of foliation in crystalline rocks

f, flat; m, moderate; s, steep

Strike of approximate vertical foliation in crystalline rocks

⟡

Drill hole, in playas

GEOLOGIC RECONNAISSANCE MAP OF PART OF THE SOUTHEASTERN MOJAVE DESERT, CALIFORNIA

By

Donald H. Kupfer and Allen M. Bassett

SCALE 1:125 000

2 0 2 4 6 MILES

CONTOUR INTERVAL 100 FEET
DATUM IS MEAN SEA LEVEL

1962

* This map was printed as Mineral Investigations Field Studies Map MF-205, by the U.S. Geological Survey; also as Plate 1 to accompany California Division of Mines and Geology Special Report 83. A Geologic Reconnaissance in the Southeastern Mojave Desert, California.

Base from Metropolitan Water District of Southern California, 1925–28

MINERAL INVESTIGATIONS
FIELD STUDIES MAP MF-205

Anticline
Showing trace of axial plane and direction of plunge of axis Dashed where approximately located

Syncline
Showing trace of axial plane and direction of plunge of axis. Dashed where approximately located

Horizontal beds

Strike and dip of foliation in crystalline rocks

Approximate strike and dip of foliation in crystalline rocks
f, flat; m, moderate; s, steep

Strike of approximate vertical foliation in crystalline rocks

Drill hole, in playas

Basalt cinder cone

KD-1
Location of fossil specimens

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Geology mapped in 1953

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